POLICY ANALYSIS AT THE DEPARTMENT OF STATE
A QUANTITATIVE METHODOLOGY

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THESIS

POLICY ANALYSIS AT THE DEPARTMENT OF STATE

A QUANTITATIVE METHODOLOGY

by

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Policy Analysis at the Department of State -

A Quantitative Methodology

by

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ABSTRACT

Foreign policy analysis is defined as an evaluation of the benefits and costs of alternative collections of overseas activities, considering the relationship of their consequences to foreign policy goals and interests. The need for a quantitative methodology to supplement traditional methods of policy analysis is discussed. A quantitative policy analysis methodology is developed which consists of: a predictive model that forecasts objectively-verifiable consequences of the proposed activities; and a weighted additive value function defined over consequences that measures the effectiveness of each alternative. The value function reflects the extent to which desired consequences are achieved by a given alternative and the relationship of desired consequences to motivating goals and interests. The problem of selecting an optimal allocation of resources and preferred mix of diplomatic activities is formulated as an integer program and a sequential algorithm is developed for its solution. Extensions to a dynamic, multi-year planning model and modifications to permit decentralized planning are discussed.

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"We do ill to exalt the powers of the human mind,
when we should seek out its proper helps."

----- Francis Bacon

I. INTRODUCTION

A. POLICY ANALYSIS AT THE DEPARTMENT OF STATE

The foreign affairs of the United States consist of a wide variety of policies, programs, and actions scattered throughout the world and conducted by many government agencies in the pursuit of numerous and often conflicting aims. Characteristic activities include bilateral economic and military assistance programs, cultural exchange programs, the informing activities of the United States Information Agency, agricultural assistance programs of the Department of Agriculture, contributions to multilateral aid programs, and diplomatic representation to governments of host countries and within international forums. In addition to his role as advisor to the President on foreign policy matters, the Secretary of State is charged with the responsibility, "to the full extent permitted by law for the overall direction, coordination and supervision of interdepartmental activities of the United States Government overseas."[1] One indispensable tool upon which the Secretary must rely for assistance in both of these roles is the policy analysis process at the Department of State.

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1. Foreign Affairs Manual Circular No. 385, based on National Security Action Memorandum 341.

While diplomacy is still very much an art, the need for a more rational process to establish the broad outlines of policy and motivate the allocation of scarce resources has been recognized by many both within and without the Foreign Service. A recent State Department management reform task force declared in its report: "Underlying all our other considerations is the principal recommendation that the Department devise and base its activities on a system which identifies U.S. interests, estimates foreign interests and environmental trends, matches U.S. strategies to the identified threats to the preservation of U.S. interests, and opportunities for their advancement, and selects and costs preferred and alternative objectives and courses of action."[2] In an introduction to a study of Planning, Programming, and Budgeting systems conducted by his Senate subcommittee Senator Henry Jackson stated, "Nowhere is the need for improved policy analysis more critical than in foreign affairs."[3]

Several attempts to improve the foreign policy analysis process have been made in the past decade. In 1965-66 the State Department experimented with a Comprehensive Country Programming System (CCPS). The system consisted primarily of a detailed breakdown of proposed expenditures into national

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2. "Diplomacy for the 70's: A Program of Management Reform for the Department of State," (Washington: USGPO) December 1970.

3. Senate Subcommittee on National Security and International Operations, committee print, "Planning-Programming-Budgeting: Interim Observations," 2 December 1968.

I. INTRODUCTION

A. POLICY ANALYSIS AT THE DEPARTMENT OF STATE

The foreign affairs of the United States consist of a wide variety of policies, programs, and actions scattered throughout the world and conducted by many government agencies in the pursuit of numerous and often conflicting aims. Characteristic activities include bilateral economic and military assistance programs, cultural exchange programs, the informing activities of the United States Information Agency, agricultural assistance programs of the Department of Agriculture, contributions to multilateral aid programs, and diplomatic representation to governments of host countries and within international forums. In addition to his role as advisor to the President on foreign policy matters, the Secretary of State is charged with the responsibility, "to the full extent permitted by law for the overall direction, coordination and supervision of interdepartmental activities of the United States Government overseas."[1] One indispensable tool upon which the Secretary must rely for assistance in both of these roles is the policy analysis process at the Department of State.

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interest and objectives categories, rather than by traditional budgetary categories. An engaging account of the birth and demise of CCPS and its short-lived successor, the Foreign Affairs Programming System (FAPS), may be found in Mosher and Harr [19]. A more recent work containing an examination of two policy analysis systems currently in use - the Country Analysis and Strategy Paper (CASP) and the Policy Analysis and Resource Allocation (PARA) system - is Reference [29]. CASP incorporates a formalized logic flow for policy analysis, based upon perceived conflicts between environmental conditions in each country and a generic list of U.S. interests. PARA is at present a heterogeneous collection of methodologies adopted by the regional bureaus. In format and content most of the PARAs (the Bureau of Inter-American Affairs excepted) are essentially extended versions of the traditional State Department policy paper. CASP serves as the PARA for the Bureau of Inter-American Affairs.

B. SHORTCOMINGS OF PAST AND PRESENT POLICY ANALYSIS SYSTEMS

The foregoing attempts to rationalize policy analysis in the State Department have met with limited success. CCPS and FAPS were ultimately abolished. The PARA program has yet to generate any significant departures from traditional methods of policy analysis. While CASP is both operational and innovative by Department standards, it nevertheless relies exclusively on qualitative analysis. The result is a document which offers little improvement in analytical quality to compensate for the significant time and effort which it requires.

From an analytical viewpoint, all of these endeavors have suffered from three principal shortcomings. The first has been the absence of a sound conceptual and analytical foundation on which to build the methodology. Dror cites the "absence of suitable goal taxonomies and value morphologies"[4] as a defect of a contemporary policy analysis. This is one facet of the conceptual weakness of previous approaches. Not only are the nature, content, and relationships among national interests and goals unclear, but the manner in which they should determine concrete objectives and policies is equally vague. Such vagueness may sometimes be a virtue in winning support for policies, but it has no place in a rational process for <u>formulating</u> policies.

The second shortcoming of past and current efforts to rationalize policy analysis is the failure or reluctance to address the problem of estimating the effectiveness of policies and programs. This shortcoming, which is closely related to the first, has resulted in part from the scarcity of suitable quantitative effectiveness measures and indicators in foreign affairs, and partly from the need inherent in policy planning to use effectiveness measures at a very high level of aggregation. Physical measures of the second type are not available in any decisionmaking context. Inability to estimate the effectiveness of proposed alternatives is a fatal defect in any policy planning and programming system, and is

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4. Yehezkel Dror, <u>Design for Policy Sciences</u>, (New York, American Elsevier Publishing Co.) 1971, p. 65.

a major reason why Aaron Wildavsky was forced to conclude that "no one knows how to do program budgeting."[5]

Inability to handle the complexity intrinsic in foreign policy analysis is the last major shortcoming of CCPS/FAPS, CASP, and PARA. As will be seen below, policy analysis requires the evaluation of alternative vectors of activities which, even when suboptimizing at relatively low levels of aggregation, such as the country level, possess many dimensions. Furthermore, activities and aims interact within and across country boundaries in very complicated ways that defy traditional methods of policy analysis.

The methodology proposed herein offers a way in which all of the foregoing analytical difficulties might be alleviated. It makes the foreign policy goal structure explicit. It provides a way to relate concrete, measurable objectives and activities to the broad policy goals and interests that motivate them. Finally, it promises to help reduce the problem of complexity by breaking multi-factor judgmental tasks into smaller subtasks that can be more easily handled by decisionmakers.

The basic approach taken in developing an explicit goal structure is to clarify vague goals, such as "national security" or "economic prosperity", by defining them in terms of progressively lower order goals until measurable objectives

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5. Aaron Wildavsky, "Rescuing Policy Analysis from PPBS", in Haveman, Robert H., and Margolis, Julius, eds., Public Expenditures and Policy Analysis, (Chicago, Markham Publishing Co.) 1970, p. 467.

are reached. The effectiveness measures developed are additive functions of weighted, abstract "satisfaction levels" of the objectives, with the weights assigned in a way that reflects the relationship between each objective and the broader motivating goals. This type of approach to policy analysis has been utilized by several authors in other fields. Chamberlain and Kingsland [5] used a goal-weighting methodology to compare alternative space programs on the basis of their contribution to space exploration goals. S. H. Dole and others in a Rand Corporation study [23] used a similar methodology for the same purpose. Another Rand study [22] established a hierarchical structure of attributes to evaluate the effectiveness of alternative transportation policies for the Northeast Corridor.

The policy analysis methodology developed in this paper is intended for use in the State Department's PARA program. It is designed as an analytical tool to assist policymakers in the discovery of sound strategies for the future. The method offers a way to refine and focus the judgments of those experienced in foreign affairs, thus incorporating in policy analysis the unique capabilities of both human judgment and formal mathematical analysis.

C. DEFINITIONS

1. Policy

A decision that has broad or significant implications, or which serves as a guide for further decisions. "Policy-making is a species of decisionmaking."[6]

2. Activity

A course of action, operation, task, or program. Typical categories of foreign affairs activities are representing, informing, rendering economic assistance, and resolving conflicts.

3. Consequence

An event which may result from the adoption of one or more alternative activities, and whose occurrence or nonoccurrence can be verified objectively. The collapse of a particular government or a ten percent increase in the number of miles of paved roads in a lesser-developed country are two examples of consequences that might ensue from overseas activities.

4. Objective

A desired consequence; an aim whose achievement can be objectively verified. Foreign affairs objectives generally fall into one of the following categories:[7]

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6. Dror, Design for Policy Sciences, p. 13.

7. This particular categorization of objectives was adapted from a management chart developed by Professor Robert von Pagenhardt for use at the Navy Management Systems Center, Monterey.

a. To achieve desired levels of performance or behavior. (Example: to prevent one state from attacking another).

b. To attain certain qualitative or quantitative standards. (Example: to raise the level of nutrition in a lesser-developed country).

c. To possess specific capabilities. (Example: to be capable of defending an ally from a given threat).

5. Goal

An abstract aim or motivating desire which is not itself operationally defined, but from which concrete objectives and activities are derived. "Access to foreign markets", "retention of key overseas bases", and "maintenance of national prestige" are examples of foreign policy goals.

6. Interest

A very broad, high order goal. "National security" and "Economic prosperity" may be thought of as national interests. No clear distinction between interests and goals is intended. The term "interest" is included because of its popularity in the policymaking community and among political scientists, and the consequent need to clarify its relationship to the concepts of goal and objective more familiar to decision theorists.

A policy may be thought of as a decision to take certain actions or to pursue certain aims. Thus the term "policy" defined above will be used frequently in this paper, as it is in the Foreign Service, to refer to both activities and the objectives or goals which they pursue.

7. Policy analysis

Evaluation of the costs and benefits of alternative collections of activities, considering the relationship of their consequences to goals and interests, for the purpose of identifying preferred policy structures. (A policy "structure" is a collection or mix of activities and their associated aims.) Yehezkel Dror [8] defines policy analysis as a "prescriptive and heuristic aid for the identification of preferred policy alternatives."[8] He notes that policy analysis includes innovation as well as evaluation of alternatives. In this paper the alternative activities which may compose a policy structure will be taken as given. Thus "policy analysis" will be confined to the design and identification of preferred mixes of activities. Policy analysis entails:

- Looking to the future.
- Examining alternatives in the light of their contribution to stated goals.
- Identifying preferred alternatives.

D. THE SYSTEMS ANALYSIS APPROACH

The policy analysis model developed in this paper is based on the "systems analysis" approach. E. S. Quade defines systems analysis as "a systematic approach to helping a decisionmaker choose among courses of action by investigating his full problem, searching out objectives and alternatives, and comparing them in the light of their consequences; it

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8. Dror, Design for Policy Sciences, p.55.

employs an appropriate framework - in so far as possible analytic - to bring expert judgment and intuition to bear on the problem."[9] The elements of a systems analysis are:

- Statement of Objectives
- Specification of alternative means of achieving the objectives
- Evaluation of the costs of each alternative
- Evaluation of the effectiveness of each alternative, relative to the objectives, through the use of a predictive model
- Ranking of the alternatives in order of preference using a criterion that relates the various dimensions of effectiveness and cost.

Most decisionmakers would agree that this is nothing more than a common sense strategy for attacking a decision problem. The methodology proposed in this paper will differ from many traditional systems analyses, however, in that subjectively-derived quantitative measures of effectiveness will be utilized where physical performance measures are not available, and when it is desired to combine dissimilar physical effectiveness measures.

The cost/benefit analytical approach employed in this paper is not the only approach that could be taken to the development of a prescriptive decision theory for foreign affairs. The fact that foreign policy must be designed to

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9. E. S. Quade, "Systems Analysis and Policy Planning," in E. S. Quade and W. I. Boucher, eds., Systems Analysis and Policy Planning (Santa Monica: The Rand Corporation) 1968, p. 2.

meet the challenges of a conflict environment might suggest game theory as a potentially fruitful approach. It is true that game theory can provide useful insights into some aspects of foreign affairs. However, in assessing the overall usefulness of the theory of games to a prescriptive decision theory, Howard Raiffa concludes: "When we depart from the extreme case in which there are two players with strictly opposing interests, game theory has very little advice to offer us."[10] One characteristic of game theory is that it attempts to prescribe optimal strategies for both actors in a conflict situation. In contrast to this jointly-prescriptive approach, the policy analysis methodology proposed herein employs what Raiffa calls a "one-sided prescriptive point of view."[11] It prescribes preferred policy decisions on the basis of a predictive model which depends in part on the use of descriptive theories of what other actors are likely to do.

Conflicts of interest are one salient feature of the policymaking environment, and uncertainty is another. Consequently the explicit treatment of uncertainty inherent in traditional Bayesian decision theory might recommend this as another possible approach to foreign policy analysis. Unfortunately, formal decision theory requires knowledge or estimation of the probability distributions of the uncertain

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10. Howard Raiffa, Decision Analysis, (Reading, Mass.: Addison-Wesley) 1970, p. 290.

11. Ibid., p. 292.

variables. Even the most devoted Bayesian would find this requirement hard to meet in foreign affairs decisionmaking. In addition, a formal treatment of uncertainty would add another order of magnitude of computational complexity to the model, thus making it extremely difficult for decision-makers to understand. Finally, the assignment of an actual probability distribution to many variables in foreign policy-making would suggest a capability for precision that does not, in fact, exist.

A more practical method of dealing with uncertainty in foreign policy analysis is to perform sensitivity analyses on the results of a deterministic model. Consequently that is the approach taken in this paper. When the consequences of an activity are uncertain, separate effectiveness computations are made for each possible consequence, or for a few representative consequences. The selection of variables and assignment of values for sensitivity testing should be based on the knowledge and judgment of experienced policy-makers, whose intuition can often suggest which variables are crucial and what their values are likely to be. In addition, due account should be given to the "robustness" of policy alternatives and to "hedging" strategies in identifying preferred alternatives.

II. FORMULATING THE PROBLEM

A. VERBAL FORMULATION

A policy analysis process may be idealized as follows:

(1) A period of time is defined during which activities are to be pursued and their consequences realized. This is called the "planning period." In the Department of State PARA program, the planning period is the approaching fiscal year.

(2) A set of consequences is formulated which policymakers desire to bring about or avoid[12] during the planning period. These desired consequences are called "objectives." Examples are "to obtain the release of all U.S. prisoners of war" and "to raise the literacy rate in country X by five percent."

(3) A list is drawn up of all the activities under the purview of the policymakers that would contribute to the achievement of one or more objectives.

(4) Limitations on the amount of resources available will ordinarily prevent the simultaneous pursuit of all desired activities. Hence various combinations of the activities on the list are examined in terms of their cost

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12. The avoidance of an event is logically equivalent to the bringing about of its complement. Hence all desired consequences can be formulated in terms of bringing about an event.

and consequences. During this process the original lists of desired consequences and feasible activities may be revised. Eventually a collection of activities is selected which appears to promise the most desirable set of consequences that can be obtained within resource constraints.

B. MATHEMATICAL FORMULATION

The preceding description of a policy analysis process will now be transformed into a more precise mathematical formulation.

1. Consequences

Each objective defines a distinct category or dimension along which similar (but less or more desirable) consequences can be imagined. An objective is the most attractive consequence in a given dimension that is considered politically and technologically feasible. Each consequence dimension is denoted by an integer $j = 1,\ldots,m$, where m is the total number of dimensions (which equals the total number of objectives).

Within a given dimension j, a particular consequence is denoted by the variable q_j. Each value of q_j represents a consequence somehow distinct from other consequences along that dimension. For instance, let j = "literacy rate among citizens of country X." Then q_j might take on values between 50 and 70 percent. When a consequence can be measured quantitatively, the units of q_j are always the physical units in which the consequence is measured (e.g., "dollars" for GNP, "dollars per person" for per-capita income). Qualitative

consequences (e.g., the occurrence or non-occurrence of an event) are represented arbitrarily by integers. Thus if j = "Egyptian reaction to UN cease-fire proposal," one possible formulation would be: $q_j = 1$ if Egyptians accept the proposal, $q_j = 0$ if they reject it. The variable q_j must take on at least two values for every j.

The objective in each consequence dimension j is the <u>most</u> desirable value of q_j, called q_{jbest}, that is considered <u>feasible</u>. Similarly, for each j the <u>least</u> desirable value of q_j that is considered <u>acceptable</u>, called q_{jworst}, is also identified. This value serves two purposes: first, it provides for the automatic elimination from further consideration of any proposed activity whose predicted consequence in dimension j is less desirable than q_{jworst}; second, it is used with q_{jbest} in constructing a relative value function over consequences (see Chapter IV).

An <u>outcome</u>, denoted $\vec{q}$, is a vector of consequences. It is defined by specifying the value of q_j for every j. Thus,

$$\vec{q} = (q_1,\ldots,q_m)$$

and $\vec{q}_{best} = (q_{1best},\ldots,q_{mbest})$, the vector of objectives.

2. <u>Activities</u>

Each different type of activity on the list of all contemplated activities is denoted by an integer $i = 1,\ldots,n$, where n is the number of different activity types. (Student exchange programs and balance-of-payments loans are examples of two different activity types.) With each activity i a

variable a_i, called the level of operation of activity i, is associated. When an activity can be described in terms of physical input or output measures, the activity level is expressed in whatever physical units seem most appropriate for describing the scale on which the activity is "operated" (e.g., number of students exchanged, or size of loan in 1972 U.S. dollars). Qualitative activity levels (for example, to take or not to take a certain action) are represented arbitratily by integers. To illustrate, if activity i is "mining of Haiphong", then one possible formulation would be: $a_i = 1$ represents the action "mine the harbor"; $a_i = 0$ represents the action "do not mine the harbor." (Transformations such as this from an event space to a number space are made solely for the purpose of notational convenience.) The variable a_i must take on at least two values for every i.

An alternative, denoted $\vec{a}$, is defined by specifying the level of operation of each of the n activities. An alternative is a vector of activity levels. Thus,

$$\vec{a} = (a_1, \ldots, a_n)$$

3. The Problem

The task of policy analysis is to find an alternative $\vec{a}$ which leads to the most desirable outcome $\vec{q}$ that can be obtained without violating any constraints. Limited resources and political considerations will likely prohibit the simultaneous realization of the most desired consequence in each dimension. This necessitates the making of value tradeoffs (considerations of relative value) among consequences as well as the prediction of consequences from activities. Policy

analysis may thus be dichotomized as follows:

(1) What outcome will result from each feasible alternative?

(2) Which of these outcomes is most desirable?

The approach taken in this paper in answering the above questions may be illustrated in this manner:

$$\begin{bmatrix} a_1 \\ \cdot \\ \cdot \\ \cdot \\ a_n \end{bmatrix} \xRightarrow{\quad F \quad} \begin{bmatrix} q_1 \\ \cdot \\ \cdot \\ \cdot \\ q_m \end{bmatrix} \xRightarrow{\quad U \quad} U(\vec{q})$$

The outcome $\vec{q}$ of each $\vec{a}$ is given by a predictive model F. A separate model predicts the cost of each $\vec{a}$. The value of each $\vec{q}$, relative to all other outcomes, is given by an evaluative model U. It is then possible to identify the alternative which leads to the greatest value of $U(\vec{q})$ without exceeding resource constraints.

The problem of predicting outcomes will be addressed in the following chapter. Evaluation of outcomes will be treated in Chapter IV. Then Chapter V will integrate these results in a quantitative policy analysis methodology.

III. PREDICTING THE CONSEQUENCES AND COSTS OF ACTIVITIES

The preceding section distinquished between two phases of policy analysis: predicting the consequences of proposed activities, and evaluating the relative desirability of consequences. The evaluative phase will be further treated in Chapter IV. This chapter addresses the problem of predicting the consequences of activities or, conversely, estimating what activities will produce a desired set of consequences. In the notation adopted in the last chapter, F is the function that predicts the outcome $\vec{q}$ of any alternative $\vec{a}$. In this chapter some observations on the general nature and sources of F will be made.

A. THE OBJECTIVITY OF A PREDICTIVE MODEL

First it should be observed that F is a representation of reality. It assumes the existence of certain relationships among real-world phenomena (activities and consequences). Hence the accuracy of F as a predictor can, at least in theory, be verified objectively by impartial scientific inquiry. This objective property of F distinguishes it from the evaluative model U which will be derived in the next chapter. The latter necessarily embodies value judgments concerning the relative desirability of consequences. While F models the real world, U models the subjective value structures of decisionmakers.

B. THE INVERSE OF A PREDICTIVE MODEL

It will be helpful to distinguish between F and its inverse, denoted F^{-1}. If a policymaker wishes to predict the consequences of a given alternative $\vec{a}$, he must use F to obtain $\vec{q} = F(\vec{a})$. Conversely, if he wishes to determine what activities should be chosen to obtain a given desired outcome, he must know F^{-1} to find $\vec{a} = F^{-1}(\vec{q})$. The model F is assumed to be a "function" in the precise mathematical sense of this term.[13] Thus F associates with each alternative a unique outcome. However, unless F is a "one-to-one"[14] function, F^{-1} will not itself be a function. When this is true, two or more alternatives may be associated with the same outcome. This should cause no difficulty, however. Since the effectiveness of an alternative will be measured (see Chapter IV) in terms of the value of its consequences, two alternatives with the same $\vec{q}$ should be equally attractive in terms of effectiveness.

C. SELECTING A PREDICTIVE MODEL

The particular F most appropriate for predicting the outcome of a given set of activities depends upon the nature of the activities. For example, various economic models are available for estimating the impact on a country's economy of economic assistance programs. Military combat models can

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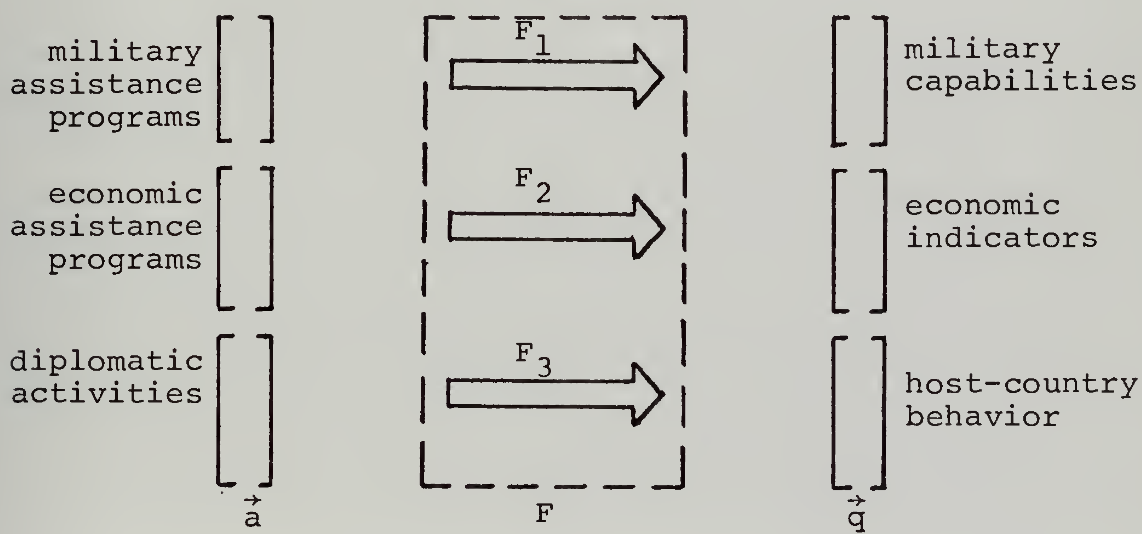
13. A <u>function</u> is a set of ordered pairs (x,y) such that each x is paired with one and only one y. The ordered pairs of F are of the form $(\vec{a},\vec{q})$.

14. A one-to-one function is a set of ordered pairs (x,y) such that each x is paired with one and only one y, and furthermore each y is paired with one and only one x.

be used to predict the consequences of maintaining various force levels and structures. The effects of a certain diplomatic action on the behavior of other states is best predicted by experienced diplomats. Here the "model" is contained implicitly in the diplomats' experience and judgment. In short, the predictive models used in policy analysis may come from a wide variety of sources and take many different forms.

Policy analysis often encompasses many different kinds of activities. In such cases F may be constructed by combining several sub-models. For instance, if the spectrum of contemplated activities includes military and economic assistance programs as well as diplomatic maneuvers, F might be composed of three sub-models as shown:



A problem which can be decomposed in this manner lends itself to the technique of suboptimization. However, interactions between the sub-models (for instance, military programs that have an economic impact) must also be taken into account.

D. COST

A special kind of consequence is the cost of an activity. In this paper it is assumed that the cost of an activity is the amount of money that it consumes. Thus the methodology implicity assumes that the scarce resources relevant to the problem can be converted to the common denominator of money. Also assumed is the availability of a cost model, C, which assigns a dollar cost, $c = C(\vec{a})$, to each alternative $\vec{a}$. While the precise form of C varies with the activities being costed, it is assumed in the next chapter to be a linear function.

IV. ASSESSING THE RELATIVE VALUE OF OUTCOMES

In this chapter a method will be proposed for assessing the relative value of each outcome $\vec{q}$ that would follow from one or more of the alternatives under consideration. "Relative value" is a quantification of the decisionmaker's preference for an outcome, relative to all other outcomes under consideration in a given analysis. The measure of value used is an additive utility function defined over the set of outcomes and constructed in a way that reflects:

(1) The extent to which each objective is satisfied in a given outcome

(2) The relative importance of the objectives in contributing to goals and interests

The evaluative model developed in this chapter is similar to one employed by F. S. Pardee and others in evaluating the effectiveness of transportation systems. The model may be described in their words:

> The procedure is quantitative throughout. However it relies heavily upon subjective inputs from responsible decisionmaking personnel. The major underlying thesis is that assessment and final choice must depend upon subjective evaluation, but that a systematic and quantitative method of making such judgments proves quite helpful.[15]

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15. F. S. Pardee et al., Measurement and Evaluation of Transportation System Effectiveness, (Santa Monica: The Rand Corporation), Sept. 1969, p. 158.

A. POLICY ANALYSIS AS AN EVALUATION OF MULTI-ATTRIBUTED ALTERNATIVES

Charles Hitch and Roland McKean, in discussing the selection of effectiveness criteria for policy problems, observe:

> Ideally we should choose that course of action which, with available resources, maximizes something like the "satisfaction" of an individual, the profits of a firm, the "military worth" of the military establishment, or the "well being" of a group..Then we would pick the policy that promised to yield the most satisfaction, the most profits, the most military worth, or the most well being... We do not have the ability to translate outcomes into such terms. In practical problem-solving, therefore, we have to look at some "proximate" criterion which serves to reflect what is happening to satisfaction or military worth. Actual criteria are the practicable substitutes for the maximization of whatever we would ultimately like to maximize.[16]

Unfortunately, such abstractions as "military worth" or "national welfare" can be adequately described only by a fairly large number of the actual or proximate criteria to which Hitch and McKean refer. Furthermore these criteria cannot generally be expressed on commensurable scales. "National security", for example, might be defined in terms of such quantities as the number of strategic missiles, army divisions, and tactical air wings possessed by the U.S. and her potential enemies. It is not possible, however, to combine these criteria into a single physical measure of military security. In short, <u>policy analysis inevitably necessitates evaluating the relative desirability of multi-dimensional vectors of physical criteria</u>.

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16. Charles J. Hitch and Roland N. McKean, <u>The Economics of Defense in the Nuclear Age</u>, (Cambridge: Harvard University Press), 1961, pp. 160-161.

The determination of preference between two multi-dimensional outcomes is often a difficult matter even for an experienced policymaker. In many cases this can present an overwhelming task for unaided subjective judgment, unless some grossly simplifying evaluative scheme is used, thereby risking the neglect of important dimensions of the problem. Peter Fishburn in Reference [11] makes the following observation on this point:

> A second practical limitation [to preference ordering a set of consequences] . . . concerns an individual's ability to state unambiguously his preference between two consequences, each of which is composed of perhaps 20 or 30 values of relevant action and outcome variables . . . Confronted by two such consequences, he may be terribly confused in attempting to comprehend "simultaneously" the consequences and may be reduced to a shrug when requested to express a preference between them.[17]

Several evaluative schemes have been developed to assist decision-makers in identifying preferences among multi-attributed alternatives. A lexicographical ordering model ranks the outcomes according to their value in the single most important outcome dimension. If two or more outcomes are equal in this dimension, the second most important dimension is used, and so forth. Herbert Simon [31] has suggested a satisficing model which tells the decisionmaker to choose the first outcome he finds each of whose component consequences is at least as desirable as a minimum satisfactory standard for that dimension. Finally, an additive utility model has been suggested in various forms by many decision theorists.

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17. Peter C. Fishburn, Decision and Value Theory, (New York: Wiley), 1964, p. 87.

(See, for example, Refs. [5], [11], [13], [33].) The additive model evaluates each outcome by summing its scores, relative to the other outcomes under consideration, in each dimension.

The lexicographical model is of limited value because in most multi-factor decision problems no single factor can be identified as of exclusive importance. Essentially this model reduces the multi-factor problem to one dimension, with the other dimensions taken into account only in case of a tie between two or more outcomes in the primary dimension. On the other hand, if a satisficing model is used and the first acceptable alternative is selected, many more attractive alternatives might be ignored. Satisficing <u>can</u> be helpful in eliminating many alternatives that are unacceptable in one or more dimensions. However, after all unacceptable alternatives have been identified, many choices may still remain. The policymaker would still like to determine which of these is most desirable. This can be accomplished using additive utilities. Consequently, one possible strategy for choosing among multi-attributed policy outcomes would be:

(1) Eliminate unacceptable alternatives using the satisficing criterion.

(2) Identify the most preferred of the remaining alternatives using an additive utility function.

In Chapter II the minimum acceptable consequence in each dimension, q_{jworst}, was defined. These values may be used in conjunction with the satisficing model to eliminate unacceptable outcomes from further consideration. An outcome

$\vec{q}$ is unacceptable if q_j is less preferred than q_{jworst} for at least one dimension j.

In the following section an additive utility model for evaluating the remaining outcomes will be developed.

B. THE ADDITIVE VALUE FUNCTION

The technique proposed herein for measuring the value of alternative policy outcomes is an application of the theory of additive utilities. The theory is used in a way that explicates policymakers' intuitive feel for the relationship between desired consequences and less well-defined goals. The purpose of the additive value function is to collapse multi-dimensional outcomes into a single dimension, thereby facilitating preference comparisons.

The assumption that the utility or value of an outcome is an additive function of the utilities of its components is a common solution to the problem of evaluating multi-attributed alternatives. For example, Efraim Turban and Morton Metersky [33] used additive utilities to determine the effectiveness of a complex aircraft system with several measures of performance. At a higher level of analysis, A. Myrick Freeman [15] suggests the use of additive weighting functions over multiple objectives for evaluating public expenditure policies.

An additive utility function takes the form:

$$U(\vec{q}) = U_1(q_1) + U_2(q_2) + \ldots + U_m(q_m) \qquad (1)$$

where $\vec{q} = (q_1, q_2, \ldots, q_m)$ is a member of the set Q of feasible outcomes; $U(\vec{q})$ is a numerical function on Q which expresses

the relative value of $\vec{q}$; and $U_j(q_j)$, $j=1,2,\ldots,m$, is a numerical function which expresses the relative value of component consequence q_j.

If P("is preferred to") is a preference relation on the set Q of multi-attributed consequences, and if $\vec{q}$ and $\vec{r}$ are two elements of Q, then the additive utility model provides:

$$\vec{q}\ P\ \vec{r} \Leftrightarrow U_1(q_1) + \ldots + U_m(q_m) > U_1(r_1) + \ldots + U_m(r_m) \quad (2)$$

The theory underlying an additive utility function is that a preference ordering among the various alternative vectors can be constructed from preference orderings on each factor or dimension. The assumptions about P and Q that imply (2) are given by Fishburn [13]. Most of them will not be treated in detail here. However, the principal assumption implicit in the additive utility approach is that the components of each outcome are <u>value-wise independent</u>. In Fishburn's words:

> In multiple-factor situations it often seems natural to think in terms of a preference order for each factor and then to wonder how these ought to be combined or synthesized into an overall preference order. However, this approach presupposes a certain kind of independence among the factors, namely that the order for a given factor is independent of the particular levels of the other factors.[18]

The assumption of factor independence requires that "the evaluator be able to make consistent value judgments about the levels of any one factor when the levels of all other factors are held fixed, and his judgment must not depend on

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18. Peter C. Fishburn, <u>Utility Theory for Decision Making</u>, (New York: Wiley), 1970, p. 42.

the particular fixed levels of the other factors."[19] This may be illustrated in the two-dimensional case as follows:

$$(c_2,d_1)\ P\ (c_1,d_1) \Leftrightarrow (c_2,d_2)\ P\ (c_1,d_2) \text{ for every } d_1,\ d_2\ .$$

$$\text{and}\quad (c_1,d_2)\ P\ (c_1,d_1) \Leftrightarrow (c_2,d_2)\ P\ (c_2,d_1) \text{ for every } c_1,\ c_2\ .$$

While these conditions are necessary to guarantee the existence of an additive utility representation for the preference relation, they are not sufficient.[20] The reader is referred to Fishburn [13] for a more rigorous treatment of additive utilities. For the purposes of this paper an intuitive grasp of the notion of factor independence will suffice.

It should quickly be pointed out that it will not always be possible to define consequences on strictly orthogonal dimensions. Hence the components of the outcome vector in a policy analysis will often not be entirely value-wise independent. However, all models are a simplification of reality, and this one is no exception. The existence of some interdependence among factors should not normally invalidate the approach. This interdependence can be held to a minimum by a judicious definition of consequences. Furthermore its effects can be evaluated subjectively, along with the other elements of the problem that were not treated by the quantitative analysis.

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19. Peter C. Fishburn, "Methods of Estimating Additive Utilities", Management Science Vol. 13, No. 7, March 1967, p. 436.

20. Fishburn, Utility Theory for Decision Making, p. 43.

The form of the additive utility model which will be employed in this paper is a <u>weighted additive value function</u>:

$$U(\vec{q}) = U_1(q_1) + U_2(q_2) + \ldots + U_m(q_m)$$
$$= w_1u_1(q_1) + w_2u_2(q_2) + \ldots + w_mu_m(q_m) \qquad (3)$$

where w_j is the "weight" or relative importance assigned to outcome dimension j. Each w_j will be derived in a way that reflects the relationship of its corresponding objective (q_{jbest}) to the broader goals that motivate policy. First, however, construction of the component value functions u_j will be discussed.

The functions u_j provide an <u>interval measure</u>[21] of the value, denoted $u_j(q_j)$, of a particular consequence q_j, relative to all other consequences in the same dimension. Since this is a <u>relative</u> value measure it can be expressed on any scale. The interval [0,1] will be used for measuring relative values. Thus u_j associates with each real consequence q_j a number between 0 and 1. Higher numbers represent more desirable consequences, and the <u>ratio</u> of the value of any two consequences indicates how much more desirable one consequence is than the other. The endpoints of the interval are defined as follows:

$$u_j(q_{jbest}) = 1 \text{ , and } u_j(q_{jworst}) = 0$$

where q_{jbest} and q_{jworst} are as defined in Chapter II.

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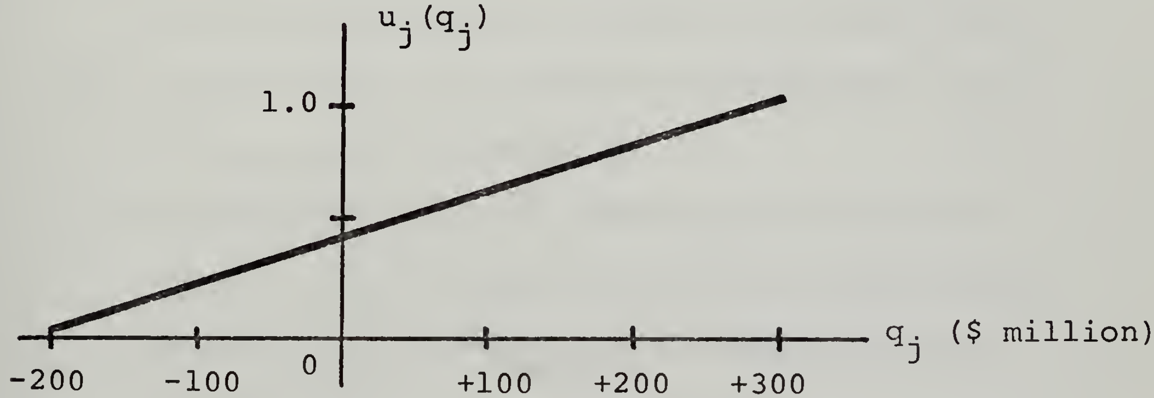
21. In an interval value measure the scale and origin of the measure may be varied without changing the relative lengths of intervals. In other words, consequence values are unique up to a linear transformation.

Component value functions may have either discrete or continuous domains. When the domain of u_j is continuous, the function can be represented by a graph (called a "worth curve" by Pardee, et al.[22]). In the illustration below suppose dimension j = "balance of payments with country X in next fiscal year". Then the worth curve for the various possible balance of payments consequences might look like this:



The above curve can be interpreted as follows: a balance of payments deficit with country X of more than $200 million is considered unacceptable, a surplus of more than $300 million is considered unlikely under any circumstances, and the value of reducing the deficit by each additional million dollars is roughly constant.

The slope of a worth curve at any point, denoted du_j/dq_j, is the marginal value of a small change along the consequence dimension. While a worth curve need not be a straight line, it will be assumed later for computational convenience and

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22. Pardee et al., Measurement and Evaluation of Transportation System Effectiveness, p. 161.

conceptual simplicity that the worth curves are linear (i.e., that du_j/dq_j is constant). This assumption means that the curve is a straight line and is completely specified by its endpoints.

If it is not desired to assume linear worth curves, one possible way of deriving the component value functions would be the following:

(1) In each dimension j all conceivable consequences (i.e., all conceivable values of q_j) are listed.

(2) From this list the bounding consequences q_{jbest} and q_{jworst} are identified.

(3) The resulting list is submitted to a panel of experts, who are asked to rank the consequences between q_{jworst} and q_{jbest} in order of their desirability.

(4) After the experts have rank-ordered the consequences, they are asked to assign each consequence a number between 0 and 1, keeping in mind the following:

  (a) The larger the number the more desirable the consequence.

  (b) The ratio between the values assigned to any two consequences is indicative of the relative extent to which one is desired over the other. For example, if $u_j(q_j^1) = 0.4$ and $u_j(q_j^2) = 0.2$, then q_j^1 is twice as desirable as q_j^2.

(5) The above procedure is repeated for each dimension j.

(6) Finally, the scores of the experts are averaged to yield a composite value $u_j(q_j)$ for each consequence in each dimension.

Each $u_j(q_j)$ is a measure of the extent to which the objective in that dimension is satisfied by consequence q_j. For instance, if $u_j(q_j) = 0.5$ for some q_j, then q_{jbest} for that dimension is said to be "50% satisfied" (since $U_j(q_{jbest}) = 1.0$ by definition). For this reason the value $u_j(q_j)$ will henceforth be called the "satisfaction level" (SL) of objective j. In addition we will let $u_j(q_j) = x_j$ for notational simplicity.

C. THE HIERARCHY OF AIMS

Derivation of the weights, w_j, in (3) is founded upon the concept of a <u>hierarchy of aims</u>. A hypothetical hierarchy of aims is portrayed in Figure 1. Each box in the figure represents a particular aim (interest, goal, or objective), labelled by a capital letter. In this example the X_j are objectives; Y_1, Y_2, and Y_3 are the goals which the objectives are intended to pursue; and Z is an idealized goal, such as "military worth" or "national welfare", which serves as the ultimate measure of value in the given context. In general a hierarchy will contain as many levels and as many aims as are considered necessary to describe the relationship between objectives and the ultimate goal.

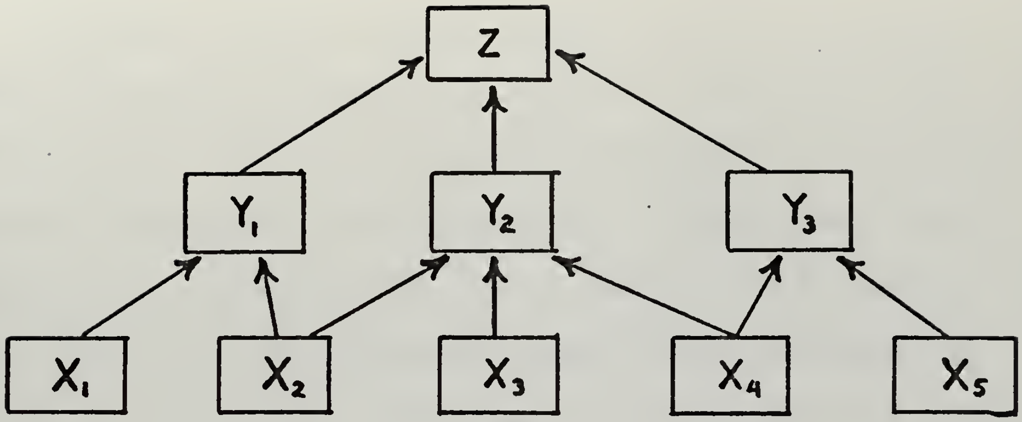

Figure 1

A hierarchy of aims of this type[23] cannot be derived or verified objectively. There exist no scientifically verifiable functional relationships between the objectives at the bottom of the hierarchy and the goals above them because the latter are abstract notions. Examples of such abstract goals are "national security", "economic prosperity", and "maintenance of national prestige". A goal hierarchy is essentially "a pictorial map of the structure of worth relationships"[24] residing within the minds of policymakers. Hence it is inherently subjective in nature. Nevertheless it offers a way in which nebulous goals that represent the "true" aims of foreign policy can be used systematically and consistently to motivate specific policies, and it makes explicit how they are so used.

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23. Another kind of hierarchy consisting solely of well-defined objectives linked by causal relationships could also be constructed. This hierarchy would be objectively derivable and would serve the function of a predictive model, predicting higher-order from lower-order consequences.

24. Pardee et al., Measurement and Evaluation of Transportation System Effectiveness, p. 31.

A variable called the satisfaction level (SL) has already been associated with each objective. Similarly a goal satisfaction level can be associated with each goal in Figure 1. Satisfaction levels are denoted by a lower-case letter. For instance, z represents the SL of goal Z, or the extent to which goal Z is fulfilled by a particular alternative.

The SL of a goal, like that of an objective, is expressed on the interval [0,1]. The SL of a goal or interest is computed, in the manner described below, as a function of the SLs of the objectives contributing to it.

The arrows, and hence the vertical dimension, in Figure 1 represent a relationship of lower to higher aims that is contributory. In other words, the achievement or level of satisfaction of a lower aim has some bearing on the achievement or level of satisfaction of the higher aims with which it is linked by an arrow. The exact nature of this contributory relationship is specified by the following mathematical model:

$$v_k = \sum_{j=1}^{J} w_{ujvk} \cdot u_j, \qquad \sum_{j=1}^{J} w_{ujvk} = 1 \qquad (4)$$

$$0 \leq w_{ujvk} \leq 1 \quad \text{for every } j,\ k$$

where

v_k is the SL of aim V_k

u_j is the SL of aim U_j

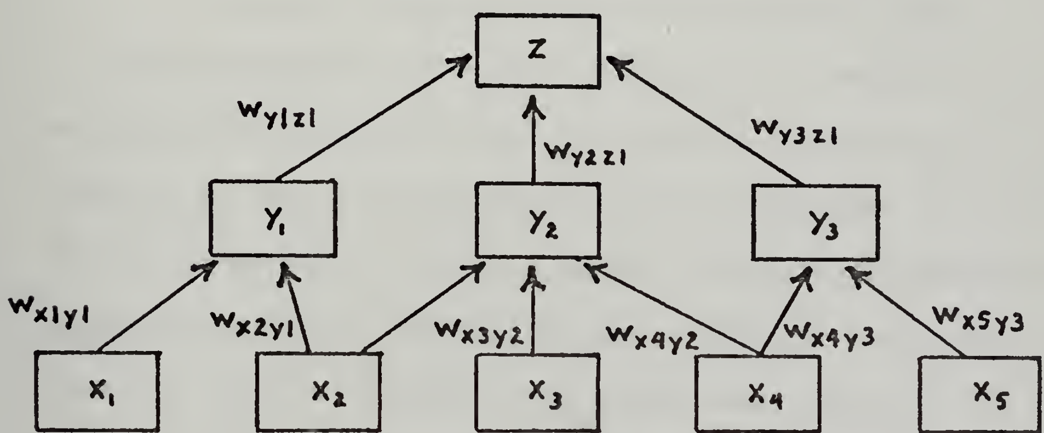
w_{ujvk} is the marginal effectiveness or "weight" assigned to aim U_j in contributing to V_j, relative to all other U-level aims that contribute to V_j. If no relationship exists between two aims, then w = 0.

J is the number of aims at the U level

For goal Y_1 in Figure 1, equation (4) would become:

$$y_1 = \sum_{j=1}^{5} w_{xjy1} \cdot x_j \, , \quad \sum_{j=1}^{5} w_{xjy1} = 1 \qquad (5)$$

Figure 2 is a reproduction of the original hierarchy with SLs and weights assigned in the appropriate places for illustration.



$$y_1 = w_{x1y1} \cdot x_1 + w_{x2y1} \cdot x_2$$
$$y_2 = w_{x2y2} \cdot x_2 + w_{x3y2} \cdot x_3 + w_{x4y2} \cdot x_4$$
$$y_3 = w_{x4y3} \cdot x_4 + w_{x5y3} \cdot x_5$$
$$z = w_{y1z1} \cdot y_1 + w_{y2z1} \cdot y_2 + w_{y3z1} \cdot y_3$$

Figure 2

The assumptions implicit in the foregoing model of goal/objective interrelationships are:

(1) The SL of a parent aim is a deterministic linear function of the SLs of its subordinate aims.

(2) The subordinate aims of a goal are substitutes for one another. The SLs of two sub-aims can be traded off at the ratio of their coefficient weights without changing the SL of the parent aims.

(3) No aim has a <u>negative</u> marginal effectiveness relative to any higher aims.

(4) All of the aims at each level of the hierarchy are compatible but independent. Any or all of them can be pursued simultaneously without influencing the accomplishment of the others.

(5) The SL of a parent aim is maximized only when <u>all</u> contributing sub-aims have maximum SLs.

The weights of the form appearing in equation (4) must be specified subjectively by a panel of experts in a manner similar to that described for the derivation of worth curves in the preceding section. Since the weights measure only <u>relative</u> marginal effectiveness, they can be expressed on an interval scale of arbitrary length and origin. In this analysis it is assumed that all weights are numbers between 0 and 1, and furthermore that the weights of all sub-aims which contribute to a given aim sum to one.

D. DERIVING FINAL WEIGHTS FOR THE ADDITIVE VALUE FUNCTION

Value function (3) is of the form

$$U(\vec{q}) = \sum_{j=1}^{m} w_j u_j(q_j) = \sum_{j=1}^{m} w_j x_j \quad .$$

In this function w_j is the marginal contribution of objective X_j, relative to <u>all</u> other objectives, to the <u>ultimate</u> aim of the hierarchy. This is termed the "final" weight of objective X_j. The weights appearing in equation (4) are "intermediate weights", which express the marginal contribution of an objective to an aim in the <u>next higher level</u> of the hierarchy,

and are relative only to the other objectives serving that aim. An objective or goal has as many intermediate weights as there are aims at the next level, though some of these may be zero. In Figure 1, for example, objective X_1 has three intermediate weights (w_{x1y1}, w_{x1y2}, and w_{x1y3}) because there are three Y-level goals, but only w_{x1y1} is non-zero.

The final weight of an objective is a function of its intermediate weights and the intermediate weights of all goals that it serves in higher levels of the hierarchy. In Figure 2, the final weight of the jth objective, w_{xjzp} ($j=1,\ldots,m$ and $p=1$), is a function of w_{xjyk} and w_{ykzp}, for all values of k. The derivation of the final weight for objective X_j is as follows:

$$z = \sum_{k=1}^{3} w_{ykzp} \cdot y_k \qquad \text{from (4)}$$

$$\text{but} \quad y_k = \sum_{j=1}^{5} w_{xjyk} \cdot x_j \qquad \text{also from (4)}$$

$$\text{so} \quad z = \sum_{k=1}^{3} w_{ykzp} \cdot \left(\sum_{j=1}^{5} w_{xjyk} \cdot x_j \right)$$

$$= \sum_{j=1}^{5} \left(\sum_{k=1}^{3} w_{xjyk} \cdot w_{ykzp} \right) \cdot x_j \qquad (6)$$

$$\text{hence} \quad w_{xjzp} = \sum_{k=1}^{3} w_{xjyk} \cdot w_{ykzp} \qquad (7)$$

In this case, (3) now becomes:

$$U(\vec{q}) = \sum_{j=1}^{5} w_{xjzp} \cdot x_j \qquad (8)$$

It can easily be shown by extending this development that the SL of the ultimate aim in any multi-level hierarchy

can be written as a weighted sum of the SLs of the objectives at the bottom of the hierarchy. Furthermore, the SL of an aim at any level of a hierarchy can be expressed in a similar fashion as a weighted sum of the SLs of all aims in any subordinate level.

The intermediate weights of all subordinate aims contributing to a particular parent aim were assumed to sum to one. It can now be shown that this relationship remains true for the final weights derived in equation (7):

$$\sum_{j=1}^{5} w_{xjzp} = \sum_{j=1}^{5} \left(\sum_{k=1}^{3} w_{xjyk} \cdot w_{ykzp} \right)$$

$$= \sum_{j=1}^{5} w_{xjyk} \sum_{k=1}^{3} w_{ykzp} = \sum_{j=1}^{5} w_{xjyk} \ . \ (1) = 1 \text{ from } (4)$$

E. NUMERICAL EXAMPLE

In order to illustrate the manner in which a hierarchy of aims is used to generate the final weights required in the additive value function, the following hypothetical example is presented. The hierarchy is the same as in Figures 1 and 2:

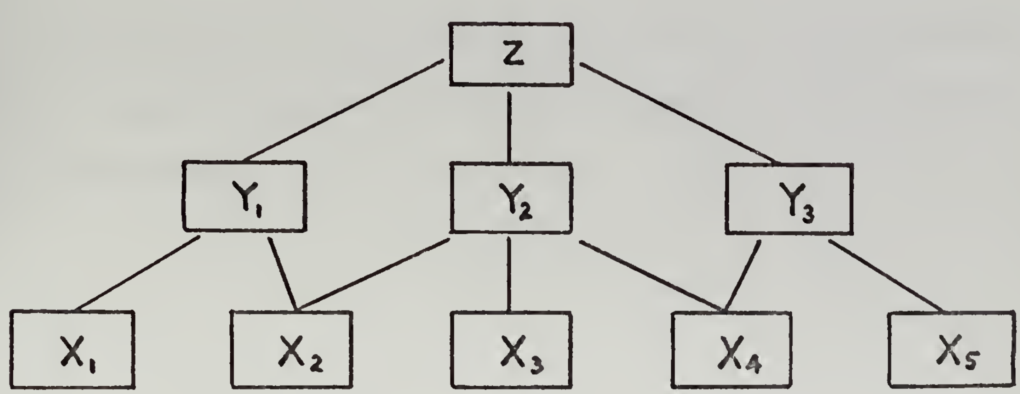


Figure 3

Consider the problem faced by a fictitious set of U.S. policymakers in planning a security assistance program for a small ally. The following qoals and objectives are assumed (refer to Figure 3):

Z = "provide defensive capability for country X adequate to meet expected threats during the planning period"

Y_1 = counter-insurgency capability

Y_2 = Defensive capability against conventional ground attack

Y_3 = capability to protect coastal shipping from naval interdiction

X_1 = expand militia forces by 200,000 men

X_2 = expand standing army by 100,000 men with proportionate increases in equipment and training

X_3 = form two armored divisions and equip with U.S. tanks

X_4 = re-equip five attack squadrons with U.S. aircraft

X_5 = double the number of coastal defense vessels in commission

It is assumed that interrogation of the policymakers has yielded general agreement on the following intermediate weights in the hierarchy:

$w_{x1y1} = 0.5$ $w_{x4y3} = 0.2$

$w_{x2y1} = 0.5$ $w_{x5y3} = 0.8$

$w_{x2y2} = 0.3$ $w_{y1z1} = 0.7$

$w_{x3y2} = 0.5$ $w_{y2z1} = 0.2$

$w_{x4y2} = 0.2$ $w_{y3x1} = 0.1$

These weights imply, for example, that upgrading conventional ground forces and militia forces are equally important in providing an adequate counter-insurgency capability. They also imply that a counter-insurgency capability is considered much more important to overall security than defense against ground or naval attacks.

From the foregoing assumptions the final weights for each objective can be computed using equation (7):

$$w_{x1z1} = \sum_{k=1}^{3} w_{x1yk}\, w_{ykz1} = .5(.7) + 0(.2) + 0(.1) = .35 = w_1$$

$$w_{x2z1} = \sum_{k=1}^{3} w_{x2yk}\, w_{ykz1} = .5(.7) + .3(.2) + 0(.1) = .41 = w_2$$

$$w_{x3z1} = \sum_{k=1}^{3} w_{x3yk}\, w_{ykz1} = 0(.7) + .5(.2) + 0(.1) = .10 = w_3$$

$$w_{x4z1} = \sum_{k=1}^{3} w_{x4yk}\, w_{ykz1} = 0(.7) + .2(.2) + .2(.1) = .06 = w_4$$

$$w_{x5z1} = \sum_{k=1}^{3} w_{x5yk}\, w_{ykz1} = 0(.7) + 0(.2) + .8(.1) = .08 = w_5$$

Observe that, as required, the final weights sum to 1.0.

It can be seen from these computations that the militia and standing army expansion objectives are considerably more

important to overall security than the other three. This effect follows from the predominant importance of the counter-insurgency goal in the hierarchy.

The final weights derived above could now be employed in a weighted additive value function to measure the value of any outcome $\vec{q} = (q_1,\ldots,q_5)$:

$$
\begin{aligned}
U(\vec{q}) &= w_1u_1(q_1) + w_2u_2(q_2) + w_3u_3(q_3) + w_4u_4(q_4) + \\
&\quad w_5u_5(q_5) \\
&= .35x_1 + .41x_2 + .10x_3 + .06x_4 + \\
&\quad .08x_5
\end{aligned}
$$

where x_j is the satisfaction level of objective X_j that corresponds to outcome q_j.

The relative desirability of any two vectors of objective SLs could now be computed. For example, let

$$\vec{x}^1 = (0.7,0.5,0.4,0.6,0.5)$$

and $$\vec{x}^2 = (0.5,0.6,0.8,0.8,0.9)$$

correspond to outcomes $\vec{q}^1$ and $\vec{q}^2$ respectively. (These outcomes in turn correspond to alternatives $\vec{a}^1$ and $\vec{a}^2$). Then

$$
\begin{aligned}
U(\vec{q}^1) &= .35(.7) + .41(.5) + .10(.4) + .06(.6) + .08(.5) \\
&= .245 + .205 + .040 + .036 + .040 \\
&= .566
\end{aligned}
$$

and
$$
\begin{aligned}
U(\vec{q}^2) &= .35(.5) + .41(.6) + .10(.8) + .06(.8) + .08(.9) \\
&= .175 + .246 + .080 + .048 + .072 \\
&= .621
\end{aligned}
$$

Thus the quantitative analysis suggests that outcome $\vec{q}^2$ is slightly preferred to $\vec{q}^1$. However, additional factors not quantified in the analysis may have to be weighed subjectively by the responsible decisionmaker.

F. SUMMARY

The procédure presented above for assessing the relative value of outcomes may be summarized as follows:

(1) Each outcome ($\vec{q}$) is transformed into a vector of objective satisfaction levels ($\vec{x}$) using the subjectively-derived component value functions $u_j(q_j) = x_j$.

(2) A hierarchy of aims is subjectively constructed, thus defining the goals and interests which all objectives under consideration are intended to serve. The relationship between aims at successive levels in the hierarchy is assumed to be given by equation (4). The hierarchy is then used, in the manner described by equation (7), to compute the final weight for each objective.

(3) The value of each outcome is then computed using the results of the two preceding steps in the weighted additive value function (3).

Subjective judgments provide inputs to the value function in two ways: first, in assigning subjectively-derived satisfaction levels to the objectives; and second, in deriving the weights assigned to each objective. One advantage of the additive value function is that it greatly simplifies

value measurement through its assumption that objective SLs can be evaluated independently of one another. Nevertheless, this advantage would be lost if the final weights could only be assigned on the basis of a simultaneous comparison of most or all of the objectives. Therefore the usefulness of a weighted additive value measure in reducing the complexity of policy analysis depends partly on the assumption that, at any level in the hierarchy, each aim is served by only a few aims in the next lower level. At the objectives level, this means that fairly small (but possibly overlapping) subsets of objectives can be identified, each of which contributes to a different goal. If there are many goals at the next level, they in turn can be divided into small subsets with different aims, and so forth. If these requirements are met, then the intermediate weights in equation (4) can be assigned subjectively without too much difficulty. From these the final weights can be computed as shown in equation (7).

In Figure 2 the largest number of dimensions a decision-maker would have to consider in assigning the intermediate weights is three, because no more than three sub-aims contribute to any one aim. On the other hand, if he had to evaluate the relative effectiveness of all of the objectives directly (i.e., assign the final weights directly), he would need to consider five dimensions simultaneously. In real-world policy analysis, of course, the outcome vector normally has many more dimensions than five.

V. A QUANTITATIVE POLICY ANALYSIS METHODOLOGY

A. CONSTRUCTING AN OPTIMAL SET OF ACTIVITIES FOR A GIVEN BUDGET

In this section the evaluative model U developed in Chapter III and the appropriate predictive model F will be integrated into a quantitative policy analysis methodology. The methodology will be capable of evaluating the relative desirability of proposed alternatives and of constructing, from a given set of component activities, the most preferred alternative that does not exceed an assumed budget.

The essential components of the methodology have already been developed: a value function U which assesses the relative value, $U(\vec{q})$, of each outcome $\vec{q}$; a predictor F which relates each alternative $\vec{a}$ to a unique $\vec{q} = F(\vec{a})$; and a cost function C that measures the dollar cost $C(\vec{a})$ of each $\vec{a}$.

It is desired to compare alternatives on the basis of their relative "effectiveness." The effectiveness, $E(\vec{a})$, of an alternative $\vec{a}$ is defined as the relative value of the outcome $\vec{q}$ which is predicted to result from the alternative. Thus:

$$E(\vec{a}) = U(\vec{q}) = U[F(\vec{a})] \tag{9}$$

Recall that an alternative $\vec{a} = (a_1,\ldots,a_n)$ is defined by specifying the level of operation, a_i, of each component activity i. It is desired to find, from among all such

vectors $\vec{a}$ whose cost does not exceed a given budget B, the one which has the greatest effectiveness. Hence the problem can be stated as:

$$\begin{aligned} &\text{Maximize} \quad E(\vec{a}) \\ &\text{Subject to} \quad C(\vec{a}) \leq B \end{aligned} \tag{10}$$

Two assumptions will now be made to simplify this problem and facilitate its solution. First it is assumed that each component activity i can be operated at only one non-zero level. This assumption implies no loss of generality for some activities (e.g., diplomatic courses of action that must be either adopted or rejected). For other activities with variable levels of operation (e.g., economic and military assistance programs wherein the amount of assistance can be varied), an appropriate level should be selected for use in the analysis. Subsequent analysis can be performed to test the effect of using a different level of operation for such activities. This assumption simplifies the problem by reducing the number of alternatives under consideration. It can be expressed mathematically as follows:

$$\text{for every activity } i, \ a_i = \begin{cases} 0 & \text{if activity } i \text{ not included in } a \\ 1 & \text{if activity } i \text{ is included in } a \end{cases}$$

Thus every $\vec{a}$ is a vector of zeroes and ones. For instance, $\vec{a} = (0,1,1,0,0)$ is the alternative that includes only activities two and three from a set of five proposed activities.

The problem now becomes:

$$\begin{array}{ll} \text{Maximize} & E(\vec{a}) \\ \text{Subject to} & C(\vec{a}) \leq B \\ & a_i = 0 \text{ or } 1 \text{ for every } i \end{array}$$

The second simplifying assumption is that each of the functions F, C, and u_j ($j = 1,\ldots,m$) is a linear function. A linear function has the following property:

$$G(\alpha\vec{x} + \vec{y}) = \alpha G(\vec{x}) + G(\vec{y}), \text{ where } \alpha \text{ is a constant.}$$

The assumption that F and C are linear implies that the consequences and cost of each activity i can be evaluated without reference to the level of operation of the other activities. The linearity of u_j implies that each worth curve, which transforms consequences into an abstract value measure, is a straight line.

The purpose of the linearity assumption is to guarantee that both the objective function $E(\vec{a})$ and the constraint equation $C(\vec{a}) \leq B$ in (10) are linear. This will permit the problem to be solved by integer programming. It will now be shown that the linearity of F and u_j imply that E is also a linear function:

$$
\begin{aligned}
E(\alpha\vec{a}^1 + \vec{a}^2) &= U[F(\alpha\vec{a}^1 + \vec{a}^2)] && \text{by def. of } E \\
&= U[\alpha F(\vec{a}^1) + F(\vec{a}^2)] && \text{by linearity of } F \\
&= U(\alpha\vec{q}^1 + \vec{q}^2) && \text{by def. of } \vec{q} \\
&= w_1 u_1(\alpha q_1^1 + q_1^2) + \ldots \\
&\qquad + w_m u_m(\alpha q_m^1 + q_m^2) && \text{by def. of } U \\
&= w_1[\alpha u_1(q_1^1) + u_1(q_1^2)] + \ldots \\
&\qquad + w_m[\alpha u_m(_m^1) + u_m(q_m^2)] && \text{by linearity of } u_j \\
&= \alpha w_1 u_1(q_1^1) + \ldots + \alpha w_m u_m(q_m^1) && \text{by rearranging terms} \\
&\quad + w_1 u_1(q_1^2) + \ldots + w_m u_m(q_m^2) \\
&= \alpha U(\vec{q}^1) + U(\vec{q}^2) && \text{by def. of } U \\
E(\alpha\vec{a}^1 + \vec{a}^2) &= \alpha E(\vec{a}^1) + E(\vec{a}^2) && \text{by def. of } E
\end{aligned}
$$

Thus $E(\vec{a})$ has been shown to be a linear function.

One further observation will permit the objective function and constraint in (10) to be written in a simpler form. Any alternative a can be written as follows:

$$
\vec{a} = \begin{bmatrix} a_1 \\ \cdot \\ \cdot \\ \cdot \\ a_n \end{bmatrix} = a_1 \begin{bmatrix} 1 \\ 0 \\ \cdot \\ \cdot \\ 0 \end{bmatrix} + \ldots + a_n \begin{bmatrix} 0 \\ \cdot \\ \cdot \\ 0 \\ 0 \end{bmatrix} = a_1\vec{e}_1 + \ldots + a_n\vec{e}_n
$$

where $\vec{e}_i$ is the unit vector is the "ith" direction.

Using this result and the linearity of E, $E(\vec{a})$ can be rewritten as:

$$
E(\vec{a}) = E(a_1\vec{e}_1 + \ldots + a_n\vec{e}_n) = a_1 E(\vec{e}_1) + \ldots + a_n E(\vec{e}_n)
$$

Similarly, $C(\vec{a})$ can be rewritten as:

$$
C(\vec{a}) = a_1 C(\vec{e}_1) + \ldots + a_n C(\vec{e}_n)
$$

Letting $C(\vec{e}_i) = c_i$ and $E(\vec{e}_i) = e_i$ for simplicity, the problem can now be stated in its final form:

$$
\begin{aligned}
&\text{Maximize} && e_1a_1 + \ldots + e_na_n \\
&\text{Subject to} && c_1a_1 + \ldots + c_na_n \leq B \\
& && a_i = 0 \text{ or } 1 \text{ for every } i
\end{aligned}
\tag{11}
$$

The solution to this elementary integer programming problem is fairly intuitive: one computes the effectiveness-to-cost ratio e_i/c_i for each resource-intensive activity i and ranks the activities according to these ratios. The activities are then selected one at a time, starting with the most cost-effective (highest e_i/c_i), until the budget is exhausted. Activities that have no resource costs (i.e., "diplomatic" activities) are formulated in mutually-exclusive sets and the activity in each set with the highest e_i is chosen. The reader is referred to Appendix A for a detailed solution to (11).

The aim of this chapter to integrate the results of Chapters III and IV in a quantitative methodology has now been accomplished. In the concluding section of the chapter means will be examined of making the basic methodology more flexible.

B. MODELLING INTERRELATIONSHIPS AMONG ACTIVITIES

Heretofore it has been assumed that the component activities are independent in the sense that the consequences of one activity can be predicted without regard to the level of operation of the other activities. In reality the following interrelationships among activities might exist:

(1) Two activities are said to be <u>complementary</u> if their effectiveness when operated jointly is greater than the sum

of their individual effectiveness. More formally, activities i and j are complementary if, and only if, $E(\vec{e}_i + \vec{e}_j) > E(\vec{e}_i) + E(\vec{e}_j)$. For example, in the improvement of educational opportunity two activities that might be considered are training better teachers and building better schools. These activities are complementary because a teacher is influenced by working conditions as well as the students, and thus is likely to teach more effectively in a modern, well-equipped school.

(2) Two activities are said to be <u>counterproductive</u> if their effectiveness when operated jointly is less than the sum of their individual effectiveness. More formally, activities i and j are counterproductive if, and only if, $E(\vec{e}_i + \vec{e}_j) < E(\vec{e}_i) + E(\vec{e}_j)$. For example, simultaneous attempts to persuade and pressure another government into taking a desired action can often be less fruitful than either approach taken individually.

(3) An activity is said to be <u>contingent</u> on another if it can be chosen only if the other is chosen. When a_i is allowed to take on only values 0 or 1, the contingency of i on j can be expressed by the constraint: $a_i \leqq a_j$. For instance, the U.S. might wish to make the sale of arms to Greece contingent upon approval of an equivalent sale to Turkey, lest Turkish fears be aroused.

(4) Two or more activities are said to be <u>mutually exclusive</u> when no alternative can include more than one of them at a positive level. Clearly two activities which are logically contradictory are mutually exclusive. If activity

i is "recognize Cuban government" and activity j is "continue suspension of diplomatic relations", these activities are mutually exclusive because they cannot both be chosen. A set of activities may also be mutually exclusive as a result of constraints inherent in the context of the problem. For example, while a defensive alliance between the U.S. and either the Soviet Union or China would not be inconceivable in certain circumstances, simultaneous alliances with both of them obviously would be unlikely. When $a_i = 0$ or 1 for every i, mutual exclusiveness can be expressed by the following constraint: $\sum_{i \varepsilon I} a_i \leq 1$, where I is a set of mutually exclusive activities.

Not all of the above interrelationships can be incorporated into the policy analysis methodology in its final form. While the complementary and counterproductive interactions are compatible with the formulation of the general problem in (10), they violate the subsequent assumption that E is a linear function. Hence formulation (11) and a linear programming solution technique cannot be used when such interactions exist. In this case the problem might be susceptible to a non-linear programming solution. However contingent and mutually exclusive relationships among activities can be modelled by the linear constraints discussed in paragraphs (3) and (4) above. Hence these additional constraints can be added to formulation (12) and the problem remains soluble by integer programming techniques.

VI. APPLICATION TO A HYPOTHETICAL POLICY ANALYSIS

In this chapter the quantitative policy analysis methodology developed in preceding chapters will be applied to a hypothetical State Department Policy Analysis and Resource Allocation (PARA) study on a fictitious country. In the interest of brevity and clarity, however, the number of objectives and courses of action will be reduced considerably in comparison with most actual PARAs.

The purposes of a country PARA are to identify U.S. interests and goals with respect to a foreign state; examine their relationship to the country's environment; and to recommend objectives, courses of action, and resource allocations for the coming fiscal year.

A. QUALITATIVE ANALYSIS

1. Background Briefing - Asianon

"Asianon" is a developing East Asian nation of moderate size. A former colonial possession of Great Britain, she has since the withdrawal of Britain from the Far East turned increasingly to the United States for economic and technical assistance for her development. While Asianon is eager for U.S. help in modernizing her armed forces as well, she has steadfastly followed a neutral foreign policy since achieving independence and is expected to continue on this course for the foreseeable future. Recently Asianon spokesmen have shown a desire to reemphasize their independence

from the American government and its policies, largely in response to a resurgent nationalism among intellectuals and factions of the military.

Asianon's size, population, mineral wealth, and location adjacent to the strategic Malunda Straits make her a potentially strong economic and military power in the region. However, many serious problems present obstacles to the realization of this potential. The country's mining industry is extremely inefficient due to antiquated equipment and the lack of expertise. Inadequate public schooling, due largely to a dearth of trained teachers, has resulted in a very low literacy rate and a scarcity of talent for economic and social development tasks. The military, which could play an important development role in the country, also suffers from a lack of trained manpower. Present military force levels are considered inadequate to meet the modest external threat of a neighbor or a determined insurgency.

2. <u>U.S. Interests and Goals vis-a-vis Asianon</u>

a. Security Interests

Asianon is considered important to U.S. national security for several reasons. First, realization of Asianon's potential self-defense capability would discourage possible aggressors and insurgencies, thereby enhancing the stability of the region. The growth of Asianon's economic power, coupled with her neutralist foreign policy, would also exert a stabilizing influence in the region. In this regard, it is important to maintain among Asianon leaders a favorable disposition toward the United States so that Asianon's growing

power will not be used to the detriment of American interests. Finally, the United States has a very strong interest in retaining unrestricted right of passage through and over the Malunda Straits. In the near future Asianon is expected to extend her claim of territorial waters out to twelve miles from her coasts. This claim would place the Malunda Straits in Asianon territorial waters. Furthermore, there are clear indications that, as a means of demonstrating her independence from the United States, Asianon may decide not to acknowledge an international right of unrestricted passage through and over the Straits. Should this occur U.S. vessels would possess only the dubious right of "innocent" passage and submerged submarines would be prohibited from transiting the Strait. Failure of the United States to retain the right of unrestricted passage through the Malunda Straits would jeopardize American security interests in the Western Pacific by potentially limiting the freedom of movement of U.S. naval forces.

In summary, U.S. security goals in Asianon for the next few years are:

(1) Develop in Asianon a self-defense capability strong enough to meet expected threats, but not so strong as to alarm her neighbors.

(2) Accelerate the economic and social development of the country.

(3) Cultivate in present and potential Asianon leaders attitudes favorable toward the U.S. and a receptiveness

to American policies and requests for cooperation.

(4) Maintain unrestricted U.S. access to all strategic waters in the region, including the Malunda Straits.

b. Economic interests

U.S. economic interests in Asianon derive mainly from her role as a source of non-strategic raw materials, her potential as an important future market for American goods and as a lucrative investment opportunity for the U.S. mining and manufacturing industries. Development of the Asianon economy and the maintenance of friendly relations between Asianon and the U.S. would advance all of these interests. Consequently U.S. economic goals in Asianon are as follows:

(1) Accelerate the economic and social development of the country.

(2) Cultivate in present and potential Asianon leaders attitudes favorable toward the U.S. and a receptiveness to American policies and requests for cooperation.

3. U.S. Objectives for the Next Fiscal Year

a. Train 10,000 additional para-military personnel to supplement Asianon Army strength. These additional men are badly needed to enhance defensive capabilities and to participate in development programs.

b. Re-equip two Asianon Army airborne brigades with U.S. weapons and equipment. Accomplishment of this objective should contribute significantly to a credible Asianon defensive capability against external threats.

c. Increase the productive capacity of the mining industry by five percent. This improvement is recognized by

Asianon leaders as absolutely essential to the further growth of their economy. Its accomplishment through U.S. assistance would be a significant factor in the maintenance of a continued U.S. influence in Asianon policy.

d. Train one thousand additional teachers for the Asianon public school system. While one thousand new teachers will have only a modest impact on educational opportunity in Asianon, this objective will help to demonstrate the sincerity of the U.S. desire to help meet the country's social needs.

e. Obtain from the government of Asianon confirmation of the right of unrestricted passage for American vessels and aircraft through and over the Malunda Straits, regardless of the territorial limit claimed by Asianon.

f. Avoid an open confrontation with the government of Asianon over any potentially-emotional issue, such as national/international rights in the Malunda Straits. Important as the Straits are to American security interests, it is felt that an open split between the two governments on this issue would do irreparable damage.

4. <u>Proposed Activities for the Next Fiscal Year</u>

In order to accomplish the foregoing objectives, the following activities have been proposed by the Country Team and the Department's Country Director for Asianon, with the concurrence of various functional bureaus and other Federal agencies. In total cost the activities would exceed any reasonably foreseeable budget allocation for the coming fiscal year. It will be the task of subsequent analysis to

select the most desirable collection of activities that can be accomodated within expected budget constraints.

a. Para-military training

(1) Military Assistance Program (MAP) grant of five million dollars making it possible for the Asianon Army to train five thousand men.

(2) Use of U.S. military advisors to train an additional five thousand men, at a total cost of four million dollars.

b. Airborne brigade re-equipment

(1) Furnish weapons and equipment costing the MAP approximately five million dollars.

c. Mining productive capacity improvement

(1) Establish three new mining operations at the sites of recently-discovered mineral deposits. This program, to be conducted under the auspices of the Agency for International Development (AID), would cost about twenty million dollars and would raise Asianon's overall mineral productive capacity by an estimated three percent.

(2) Furnish American technical advisors for existing Asianon mines at a total cost of 12 million dollars.

(3) Contribute fifteen million dollars to the United Nations Development Fund for technical assistance programs in Asianon. It is roughly estimated that these last two activities will each provide about a one percent improvement in Asianon's mineral productive capacity.

d. Teacher training

(1) A proposed AID training program costing two million dollars could provide five hundred new teachers.

(2) Another five hundred teachers could be trained using Peace Corps volunteers. This would cost about five million dollars.

e. Malunda Straits

Two alternative actions are under consideration to resolve this problem. One is to inform the Asianon government of the impossibility of obtaining U.S. Congressional support for future military and economic assistance if Asianon were to claim the Malunda Straits as territorial waters without acknowledging an international right of free passage. This action would probably evoke the desired guarantee, but only at the cost of poisoning the currently amicable relations of the two countries. The second alternative is to ignore the problem and hope for the best. It is very likely that this course will result in an Asianon claim to the Straits, subject only to the ambiguous right of innocent passage for ships on the surface.

B. QUANTITATIVE ANALYSIS

This section will consist of a quantitative analysis of U.S. policies vis-a-vis Asianon, utilizing the methodology developed in the preceding chapters. The purpose of the analysis will be to select the most effective mix of activities that can be accomplished within assumed budget constraints. In order to allow for uncertainties in the budgetary process,

the optimal "alternative" (mix of activities) will be identified for allocations of ten, twenty-five, and fifty million dollars for U.S. programs in Asianon.

1. Hierarchy of Aims vis-a-vis Asianon

Figure 4 portrays the interests, goals, and objectives discussed in the qualitative analysis, and their interrelationships. An arrow is drawn from each objective or goal to every higher aim to which it contributes. The number adjacent to each arrow is the intermediate weight associated with the two aims. The intermediate weights are summarized below.

$w_{x1y1} = 0.4$

$w_{x2y1} = 0.6$

$w_{x1y2} = 0.3$

$w_{x3y2} = 0.6$

$w_{x4y2} = 0.1$

$w_{x3y3} = 0.2$

$w_{x4y3} = 0.2$

$w_{x5y3} = 0.6$

$w_{x6y4} = 1.0$

$w_{y1z1} = 0.2$

$w_{y2z1} = 0.1$

$w_{y3z1} = 0.3$

$w_{y4z1} = 0.4$

$w_{y2z2} = 0.4$

$w_{y3z2} = 0.6$

$w_{z1v1} = 0.7$

$w_{z2v1} = 0.3$

(All intermediate weights not specifically listed are zero.)

2. Component Value Functions

The worth curve in Figure 5 assign an objective satisfaction level to each possible consequence of the proposed activities. Since it was assumed earlier that the component value functions are linear, the worth curves may be drawn by

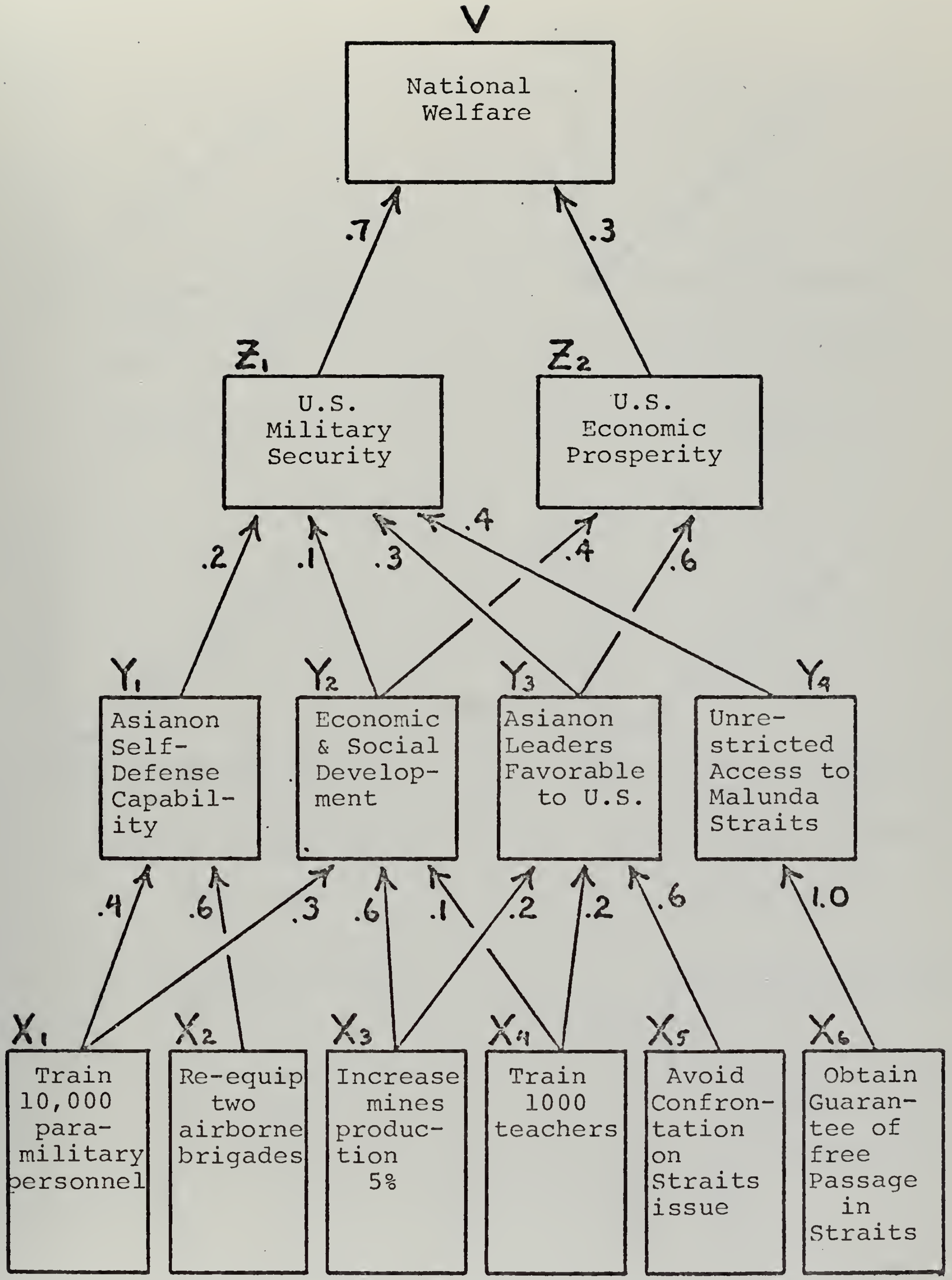


Figure 4: Hierarchy of Aims for Asianon PARA

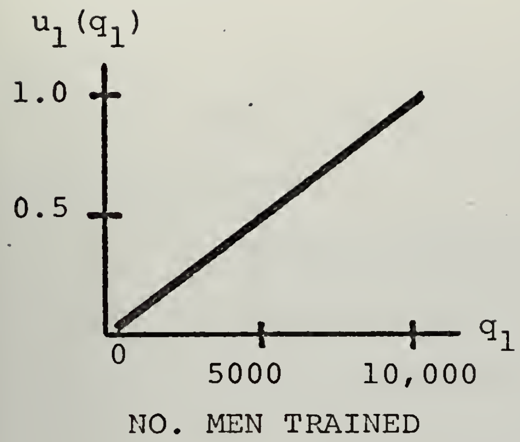


Figure 5a.

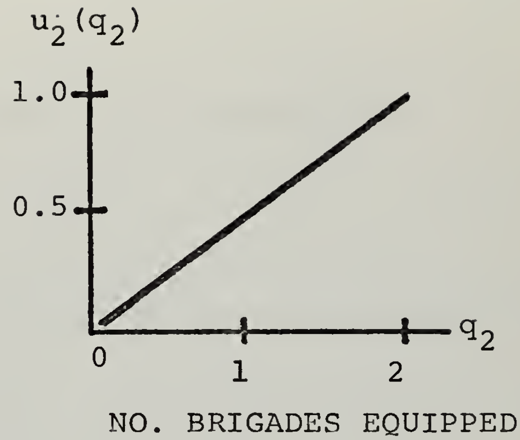


Figure 5b.

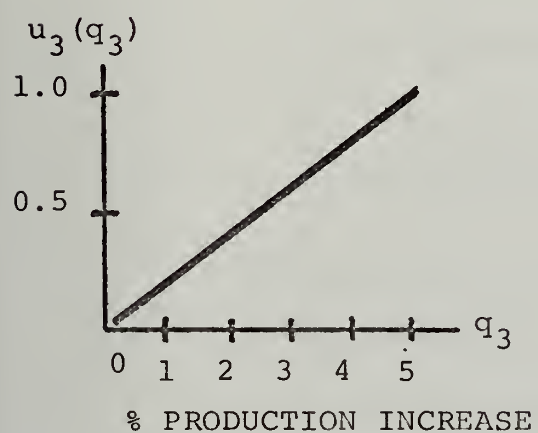


Figure 5c.

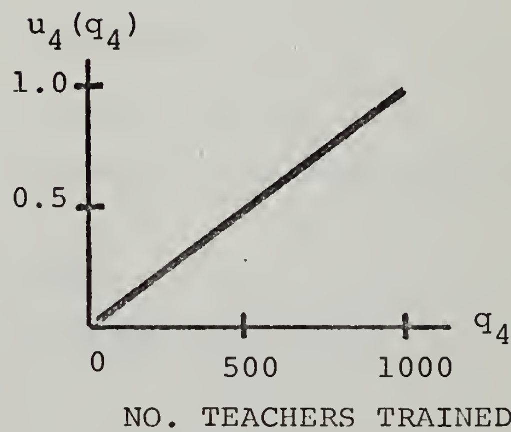


Figure 5d.

$$q_5 = \begin{cases} 1 & \text{If Confrontation Avoided} \\ 0 & \text{If Confrontation Not Avoided} \end{cases}$$

$$u_5(q_5) = \begin{cases} 1.0 \text{ for } q_5 = 1 \\ 0.0 \text{ for } q_5 = 0 \end{cases}$$

Figure 5e.

$$q_6 = \begin{cases} 0 & \text{If Asianon Restricts Straits Passage} \\ 1 & \text{If Unrestricted Passage Guaranteed} \end{cases}$$

$$u_6(q_6) = \begin{cases} 1.0 \text{ for } q_6 = 1 \\ 0.0 \text{ for } q_6 = 0 \end{cases}$$

Figure 5f.

Figure 5: Component Value Functions

connecting the values $u_j(q_{jworst})=0$ and $u_j(q_{jbest})=1$. These values, like the intermediate weights in the hierarchy of aims, were obtained by interrogating the responsible policymakers.

3. Summary of Notation

(1) There are seven goals/interests in the hierarchy:

V (National Welfare)

Z_1 (U.S. Military Security)

Z_2 (U.S. Economic Prosperity)

Y_1 (Asianon self-defense capability)

Y_2 (Economic/Social Development)

Y_3 (Asianon leaders favorable to U.S.)

Y_4 (Unrestricted U.S. access to Malunda Straits)

(2) There are six objectives:

X_1 (Para-military training)

X_2 (Army re-equipment)

X_3 (Increase productive capacity)

X_4 (Teacher training)

X_5 (Avoid confrontation on Straits issue)

X_6 (Obtain guarantee of unrestricted passage in Straits)

(3) There are ten proposed activities:

1 (MAP training grant)

2 (Training by U.S. advisors)

3 (MAP re-equipment program)

4 (AID construction program)

5 (AID advisory program)

6 (UNDP technical assistance grant)

7 (AID teacher training program)

8 (Peace Corps teacher training)

9 (Ignore potential problem over Straits access)

10 (Threaten cutoff of future assistance)

(4) An <u>alternative</u> is a vector of activity levels:

$$\vec{a} = (a_1, a_2, a_3, a_4, a_5, a_6, a_7, a_8, a_9, a_{10})$$
$$a_i = 0 \text{ or } 1 \text{ for all } i$$

An <u>outcome</u> is a vector of consequences:

$$\vec{q} = (q_1, q_2, q_3, q_4, q_5, q_6)$$

An outcome can be transformed to a vector of objective satisfaction levels using the component value functions $u_j(q_j) = x_j$ (the satisfaction level of objective X_j):

$$\vec{x} = (x_1, x_2, x_3, x_4, x_5, x_6)$$
$$0 \leq x_j \leq 1 \text{ for all } j$$

4. <u>Prediction of Consequences</u>

Based upon the information contained in the qualitative analysis, consequences of the proposed activities may be predicted. Let $\vec{e}_i$ be the alternative that includes only the ith proposed activity, and let $\vec{q}^{\,i}$ be the outcome of alternative $\vec{e}_i$.

$\vec{q}^1 = F(\vec{e}_1) = (5000,0,0,0,0,0)$ $\vec{q}^2 = F(\vec{e}_2) = (5000,0,0,0,0,0)$

$\vec{q}^3 = F(\vec{e}_3) = (0,2,0,0,0,0)$ $\vec{q}^4 = F(\vec{e}_4) = (0,0,3,0,0,0)$

$\vec{q}^5 = F(\vec{e}_5) = (0,0,1,0,0,0)$ $\vec{q}^6 = F(\vec{e}_6) = (0,0,1,0,0,0)$

$\vec{q}^7 = F(\vec{e}_7) = (0,0,0,500,0,0)$ $\vec{q}^8 = F(\vec{e}_8) = (0,0,0,500,0,0)$

$\vec{q}^9 = F(\vec{e}_9) = (0,0,0,0,0,1,0)$ $\vec{q}^{10} = F(\vec{e}_{10}) = (0,0,0,0,0,1)$

Using the worth curves derived above, each outcome can be converted to a vector of objective satisfaction levels. Let $\vec{x}^i$ denote the vector of SLs resulting from alternative $\vec{e}_i$.

$\vec{x}^1 = (.5,0,0,0,0,0)$ $\vec{x}^2 = (.5,0,0,0,0,0)$

$\vec{x}^3 = (0,1.0,0,0,0,0)$ $\vec{x}^4 = (0,0,.6,0,0,0)$

$\vec{x}^5 = (0,0,.2,0,0,0)$ $\vec{x}^6 = (0,0,.2,0,0,0)$

$\vec{x}^7 = (0,0,0,.5,0,0)$ $\vec{x}^8 = (0,0,0,.5,0,0)$

$\vec{x}^9 = (0,0,0,0,1.0,0)$ $\vec{x}^{10} = (0,0,0,0,0,1.0)$

5. <u>Derivation of Final Weight for Each Objective</u>

The final weights are computed using the intermediate weights from Figure 4 in equation (7) of Chapter IV. Only representative calculations will be presented here. Detailed calculations for all of the weights may be found in Appendix B.

$$w_{x1z1} = w_{x1y1}w_{y1z1} + w_{x1y2}w_{y2z1} + w_{x1y3}w_{y3z1} + w_{x1y4}w_{y4z1}$$

$$= .4(.2) + .3(.1) + 0(.3) + 0(.4) = 0.11$$

Summary:

$w_{x1z1} = 0.11$	$w_{x1z2} = 0.12$
$w_{x2z1} = 0.12$	$w_{x2z2} = 0$
$w_{x3z1} = 0.12$	$w_{x3z2} = 0.36$
$w_{x4z1} = 0.07$	$w_{x4z2} = 0.16$
$w_{x5z1} = 0.18$	$w_{x5z2} = 0.36$
$w_{x6z1} = 0.40$	$w_{x6z2} = 0$
$\sum_{j=1}^{6} w_{xjz1} = 1.00$	$\sum_{j=1}^{6} w_{xjz2} = 1.00$

$$w_1 = w_{x1v1} = w_{x1z1}w_{z1v1} + w_{x1z2}w_{z2v1} = .11(.7) + .12(.3)$$

$$= .113$$

Summary (Final Weights):

$w_1 = .113$	$w_2 = .084$
$w_3 = .192$	$w_4 = .097$
$w_5 = .234$	$w_6 = .280$

$$\sum_{j=1}^{6} w_j = 1.00$$

Using the final weights in equation (3) of Chapter IV, the weighted additive value function for this problem can now be written:

$$U(\vec{q}) = \sum_{j=1}^{6} w_j u_j(q_j)$$

$$= .113x_1 + .084x_2 + .192x_3 + .097x_4 + .234x_5 + 280x_6$$

6. <u>Computation of Activity Effectiveness Coefficients</u>

Individual activity effectiveness coefficients for use in formulation (11) of Chapter V can now be computed, using the additive value function and the outcomes listed in paragraph 4 above. Refer to Appendix B for complete calculations.

$$e_1 = E(\vec{e}_1) = U[F(\vec{e}_1)] = U(\vec{q}^{\,1})$$

$$= .113x_1^1 + .084x_2^1 + .192x_3^1 + .097x_4^1 + .234x_5^1 + .280x_6^1$$

$$= .113(.5) + .084(0) + .192(0) + .097(0) + .234(0) + .280(0)$$

$$= .0565$$

Summary of Effectiveness Coefficients:

e_1 = .0565 (Military training under MAP)	e_2 = .0565 (Military training by U.S. advisors)
e_3 = .0840 (Army re-equipment)	e_4 = .1152 (AID construction)
e_5 = .0384 (AID technical advisors)	e_6 = .0384 (UNDP grant)
e_7 = .0485 (AID teacher training)	e_8 = .0485 (Peace Corps teacher training)

e_9 = .2340 (Ignore Straits problem) e_{10} = .2800 (threaten cutoff of assistance)

7. Mathematical Formulation of Problem

The problem can now be formulated in the format of (11) in Chapter V. The cost coefficients are taken from the cost information in the qualitative analysis. Two kinds of mathematical constraints on the problem exist. One is a budget constraint, which requires that the total cost of all the activities chosen in the optimal alternative must not exceed the given budget. This constraint can be written as: $\sum_{i=1}^{10} c_i a_i \leq B$. The second is a logical constraint: activities 9 and 10 are mutually exclusive, since they obviously cannot both be included in the same alternative. This constraint can be written as: $a_9 + a_{10} \leq 1$.

The final formulation is as follows:

Maximize $.0565a_1 + .0565a_2 + .0840a_3 + .1152a_4 + .0384a_5 + .0384a_6 + .0485a_7 + .0485a_8 + .2340a_9 + .2800a_{10}$

Subject to $5a_1 + 4a_2 + 5a_3 + 20a_4 + 12a_5 + 15a_6 + 2a_7 + 5a_8 \leq B$

$a_9 + a_{10} \leq 1$

$a_i = 0$ or 1 for all i

The problem will be solved for values of B = \$1 \$50-million.

8. Solution

a. Effectiveness/Cost Ratios

The effectiveness/cost ratio for each activity is computed as follows:

$e_1/c_1 = .0565/5 = .0113$ $\qquad$ $e_2/c_2 = .0141$

$e_3/c_3 = .0168$ $\qquad$ $e_4/c_4 = .0058$

$e_5/c_5 = .0032$ $\qquad$ $e_6/c_6 = .0025$

$e_7/c_7 = .0248$ $\qquad$ $e_8/c_8 = .0097$

This ratio is not defined for activities 9 and 10, since $c_9 = c_{10} = 0$.

b. Allocation of Resources

Budget money is allocated to the activities in the order of their effectiveness/cost ratios, starting with the highest, until the budget has been exhausted.

Activity	e_i/c_i	Cost ($ millions)	Running Cost Total
7 (AID teacher training)	.0248	2	2
3 (Army re-equipment)	.0168	5	7
			____$10 million
2 (Military training by U.S. advisors)	.0141	4	11
1 (Military training under MAP)	.0113	5	16
8 (Peace Corps teacher training)	.0097	5	21
			____$25 million
4 (AID construction)	.0058	20	41
			____$50 million
5 (AID technical advisors)	.0032	12	53
6 (UNDP grant)	.0026	15	66

If the Asianon country program is budgeted at $10 million, the optimal alternative includes only activities 3 and 7; for a $25 million budget activities 1, 2, and 8 can

be added; and for a \$50 million budget, activity 4 can also be adopted. If desired, the proposed activities can now be modified and the analysis repeated. For example it might be desired to adjust the scale and costs of activities 2, 3, and 7 so that all three of them can be fitted within a \$10 million budget.

c. Selection of Preferred Diplomatic Action

In accordance with the solution technique contained in Appendix A, the diplomatic action with the highest effectiveness coefficient should be preferred. Since e_9 = .2340 and e_{10} = .2800, the quantitative analysis indicates that activity 10 (threaten cutoff of assistance to obtain guarantee of unrestricted free passage in Malunda Straits) is preferred to activity 9.

d. Summary of Optimal Solutions

Let $\vec{a}^*_{low}$, $\vec{a}^*_{mid}$, and $\vec{a}^*_{high}$ be the optimal alternatives for the \$10, \$25, and \$50 million budgets respectively. Then:

(1) $\vec{a}^*_{low} = (0,0,1,0,0,0,1,0,0,1)$. This alternative includes the preferred diplomatic measure (activity 10 - threaten cutoff of assistance), and the \$10 million budget is distributed between activities 3 (Army re-equipment) and 7 (AID teacher training).

(2) $\vec{a}^*_{mid} = (1,1,1,0,0,0,1,1,0,1)$. Activities 1 (military training under MAP), 2 (military training by U.S. advisors), and 8 (Peace Corps teacher training) are added to the programs included in $\vec{a}^*_{low}$.

(3) $\vec{a}^*_{high} = (1,1,1,1,0,0,1,1,0,1)$. Activity 4 (AID construction) is added to the programs included in $\vec{a}^*_{mid}$.

These solutions are "optimal" only for the proposed activities as originally formulated, and only on the basis of the factors explicitly included in the quantitative analysis. A re-definition of activities could lead to different solutions. In addition, the subjective incorporation of additional factors into the analysis might generate other solutions which may be preferable.

9. Concluding the Analysis

To complete the quantitative analysis of this problem, the optimal solutions should be recomputed using different values for some of the goal weights and assuming different consequences for activities with uncertain outcomes. The results of such sensitivity analyses should indicate the assumptions about goal weights and consequences to which the optimal solutions are most sensitive. These assumptions could then be subjected to closer judgmental scrutiny. In addition, solutions that are optimal or near-optimal for a wide variety of assumptions can also be identified.

The final results of the quantitative analysis would comprise only one part of a thorough policy analysis of the hypothetical problem. The quantitative results should be interpreted subjectively by experienced policymakers and modified as necessary in the light of other factors (such as other-country effects of certain activities and the effect of domestic political considerations) not incorporated in the formal analysis.

VII. EXTENSIONS AND CONCLUSIONS

In this concluding chapter two analytical extensions of the proposed quantitative policy analysis methodology are discussed. The modifications increase the flexibility of the methodology and render it more suitable for the State Department's Policy Analysis and Resource Allocation (PARA) process. Lastly, some of the virtues and defects of the quantitative methodology are summarized and an overall assessment offered of its merits and utility for PARA.

A. EXTENSIONS TO THE METHODOLOGY

1. A Dynamic Model

In the methodology described in preceding chapters, the selection of activities for each fiscal year was treated as a decision problem independent of earlier country programs and anticipated future objectives. In reality a PARA must be designed to build upon previous accomplishments, to lay the groundwork for future activities, and to keep options open. The objectives in a given year are desired not only for the immediate benefits which they generate, but also for their contributions to anticipated future objectives. Similarly, activities pursued in a given year may have consequences in several future years. In short policy analysis is a dynamic process. The time considerations which were incorporated subjectively in the original methodology could be treated explicitly in a policy analysis methodology based

upon a dynamic predictive model and an evaluative model that includes time preferences for consequences.

One possible approach to a dynamic methodology would be the following: assume a multi-year planning period of T years, with alternatives $\vec{a}^t$ and outcomes $\vec{q}^t$ defined for each year t (t = 1,...,T). A sequence of alternatives $\vec{a} = (\vec{a}^1, \vec{a}^2, \ldots, \vec{a}^T)$ is called a "strategy" and the corresponding sequence of outcomes $\vec{q} = (\vec{q}^1, \vec{q}^2, \ldots, \vec{q}^T)$ an "outcome stream". A relative value function U is defined over outcome streams, so that $U(\vec{q}^1, \ldots, \vec{q}^T)$ is the present value of realizing $\vec{q}^t$ in year t, for t = 1,...,T. The outcome achieved in a given year t would in general be a function of the state of affairs at the beginning of the year (i.e., the outcome of the previous year's activities) and the alternative adopted for t. Hence, $\vec{q}^t = F(\vec{a}^t, \vec{q}^{t-1})$. The problem could now be formulated as:

$$\begin{array}{lll} \text{Find } \vec{a} \text{ to maximize} & U(\vec{q}^1, \ldots, \vec{q}^T) & \\ \text{Subject to} & c(\vec{a}^t) \leq B^t & \text{for all } t \\ & \vec{q}^t = F(\vec{a}^t, \vec{q}^{t-1}) & \text{for all } t \end{array}$$

where B^t is the budget constraint anticipated in year t. One could now proceed in the manner of Chapter V to make assumptions about the form of U and F and to develop a solution algorithm using the principles of dynamic programming.

The explicit treatment of time considerations in a dynamic formulation would add flexibility to the policy analysis methodology, but only at the cost of considerably increasing its complexity.

2. Extensions of Country-based Methodology to Regional and Global PARAs

Regional and global policy analyses could be done in either of two ways: by aggregating several country-level PARAs, or by starting anew using the same approach as in the country-level PARA. The first method has the advantage of simplicity and is readily adaptable to decentralized policy-making. The second method relates country objectives to regional and global goals more explicitly.

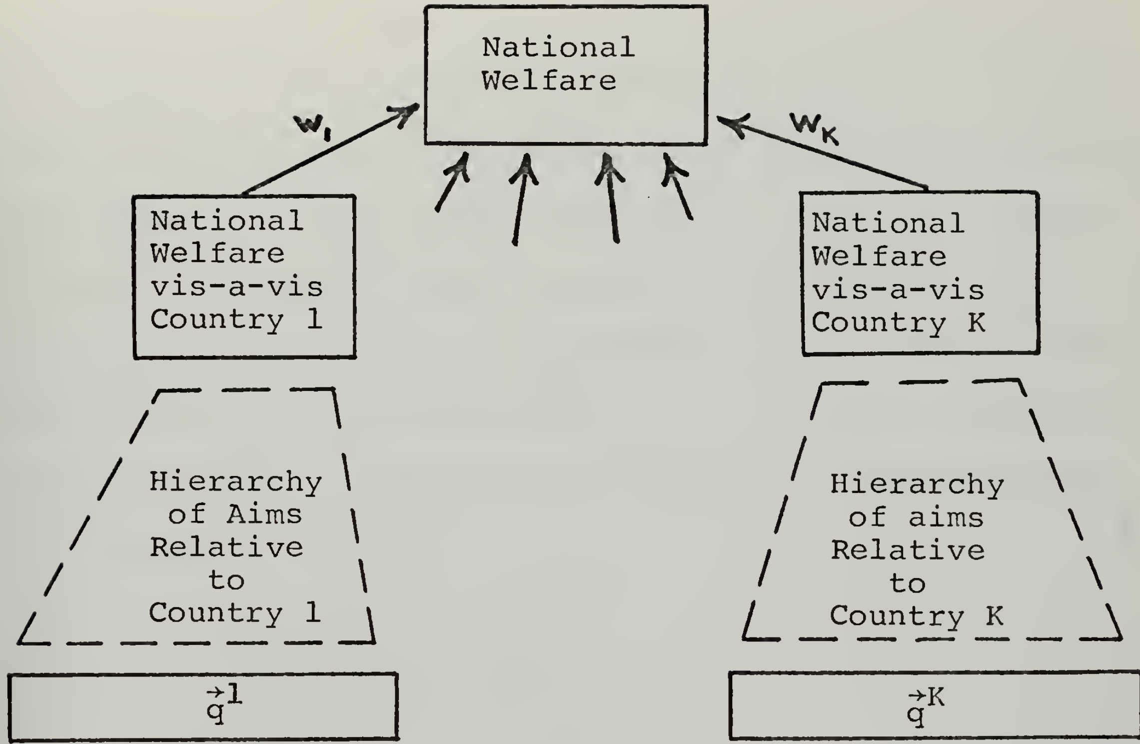
In the ensuing discussion let there exist K countries, each denoted by the index $k = 1,\ldots,K$; let $\vec{a}^k$ and $\vec{q}^k$ be the alternative and predicted outcome in the kth country in a given year.

a. Regional/Global Analysis Method I

A unique hierarchy of aims, and hence a unique relative value function U_k, is defined for each country. In addition, each country is assigned a weight w_k representing its relative importance to the overall national interest, such that $\sum_{k=1}^{K} w_k = 1.0$ and $0 \leq w_k \leq 1$. The relative value of an aggregate vector of outcomes $\vec{q} = (\vec{q}^1,\ldots,\vec{q}^K)$ is defined as a weighted sum of the relative values for each country:

$$U(\vec{q}) = U(\vec{q}^1,\ldots,\vec{q}^K) = \sum_{k=1}^{K} w_k U_k(\vec{q}^k)$$

This approach has the effect of adding a new level to the hierarchy of aims:



The problem of selecting an optimal aggregate alternative $\vec{a} = (\vec{a}^1,\ldots,\vec{a}^K)$, assuming a fixed total budget B, could be written as:

$$\text{Maximize} \quad \sum_{k=1}^{K} w_k U_k(\vec{q}^{k})$$

$$\text{Subject to} \quad \sum_{k=1}^{K} c(\vec{a}^{k}) \leq B$$

The solution to this problem would include the optimal distribution of funds between countries as well as among activities within each country. "Other-country" effects (consequences relative to a country that proceed from activities in another country) can also be modelled in this formulation by appropriate structuring of the aggregate predictive model F.

Method I for regional/global analysis may be modified to permit its use in a decentralized, iterative policymaking process. In this process each Country Team/ Country Director would have the responsibility of allocating his budget B_k so as to maximize $U_k(\vec{q}^k)$. At each iteration of the process, the central planners would decide upon a budget distribution $(B_1,\ldots,B_K)$ among the K countries such that the sum of all B_k was equal to B, the total regional or global budget. Using these constraints, country teams would solve the problem:

$$\begin{array}{ll} \text{Maximize} & U_k(\vec{q}^k) \\ \text{Subject to} & c(\vec{a}^k) \leq B_k \end{array}$$

In solving this problem the marginal value to the country program, dU_k^*/dB_k, of an additional increment of funds could be determined. From this the marginal change in the optimal value of the <u>aggregate</u> value function could be computed:

$$\frac{dU^*}{dB_k} = \frac{d}{dB_k} \sum_{k=1}^{K} w_k U_k^* = w_k \frac{dU_k^*}{dB_k}$$

The central planners would use this information to compute a new budget distribution, giving more money to country programs with high values of $w_k \dfrac{dU_k^*}{dB_k}$ and less money to programs with low values. The optimal budget distribution among

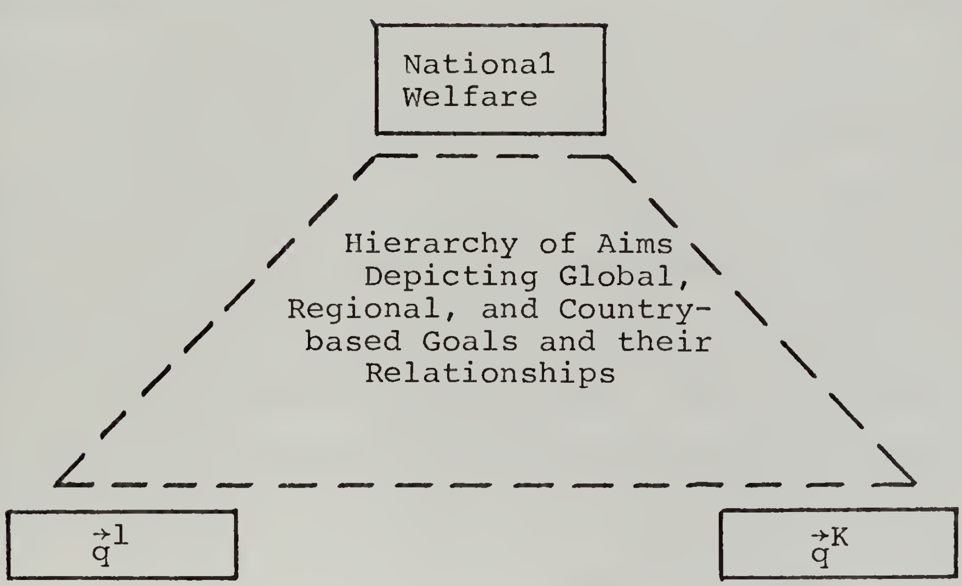
countries (i.e., the values of $B_1, \ldots, B_K$ that maximize $U(\vec{q})$) would result when all $w_k \frac{dU_k^*}{dB_k}$ are <u>equal</u>.[25]

b. Regional/Global Analysis Method II

A new hierarchy of aims is defined which replaces the individual hierarchies defined for each country. The new hierarchy incorporates regional and global goals as well as country-oriented goals. Thus it explicates the relationship between the former and country-based goals and objectives. The new composite hierarchy generates a new relative value function U which is defined over an aggregate vector of outcomes:

$$U(\vec{q}) = U(\vec{q}^{\,1}, \ldots, \vec{q}^{\,K})$$

This approach may be illustrated as follows:



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25. See Appendix C for proof of this assertion.

The problem of selecting an optimal aggregate alternative $\vec{a}$ for a given budget could be written as:

$$\text{Maximize} \quad U(\vec{q}^{\,1}, \ldots, \vec{q}^{\,K})$$
$$\text{Subject to} \quad \sum_{k=1}^{K} c(\vec{a}^{\,k}) \leq B$$

B. CONCLUSIONS

1. <u>Advantages of Quantitative Methodology</u>

The quantitative methodology proposed in this paper offers the following advantages over traditional methods of policy analysis:[26]

(1) Goals, objectives, and their priorities are explicitly stated.

(2) All of the relevant dimensions of the decision are incorporated into the analysis. The human tendency to concentrate on relatively few aspects of a complicated decision at the expense of the others is avoided.

(3) The methodology is capable of handling finer levels of discrimination in the importance of aims or the effectiveness of activities than is possible with qualitative analysis.

(4) The methodology provides a way of linking concrete objectives and activities to the vaguely-defined goals of foreign policy.

(5) If computerized the methodology would be capable of examining quickly and easily many more alternatives than

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26. This section draws in part on a paper by Mr. John K. Wilhelm of the Department of State presented at the 25th Military Operations Research Society Meeting, 17 June 1970, New London, Connecticut.

would ever be possible using traditional methods.

2. <u>Disadvantages of Quantitative Methodology</u>

Disadvantages of the quantitative methodology are as follows:

(1) The simplifications of reality that are necessary to make the mathematics tractable, such as the assumption that objectives are independent of one another, introduce distortions into the analysis. These distortions must be corrected by subjective, qualitative assessment of the quantitative results.

(2) Quantification of some of the subjective factors in the analysis, such as the weights to be assigned to military security and economic prosperity, is a difficult judgmental task. In addition, policymakers feel an understandable reluctance to discuss such politically-sensitive factors in explicit, quantitative terms.

In conclusion, both qualitative and quantitative methods of analysis possess unique advantages and disadvantages. A well-designed policy analysis system should be a blend of both techniques. The methodology proposed in this thesis is offered in the hope that it will contribute to the development of more systematic, quantitative techniques of policy analysis at the Department of State.

APPENDIX A

SELECTION OF OPTIMAL ALTERNATIVE VECTOR OF ACTIVITY LEVELS IN PROBLEM (11) OF CHAPTER V

The problem may be written in a more general form as:

$$\text{Maximize} \quad e_1a_1+\ldots+e_na_n+e_{n+1}a_{n+1}+\ldots+e_{n+d}a_{n+d}$$

$$\text{Subject to} \quad c_1a_1+\ldots+c_na_n \leq B$$

$$\sum_I a_i = 1 \quad \text{for each set I of mutually-exclusive diplomatic activities}$$

$$a_i = 0 \text{ or } 1 \text{ for every } i$$

where $i=1,\ldots,n$ are the subscripts of the resource-intensive activities, and $i=n+1,\ldots,n+d$ are the subscripts of the diplomatic courses of action, which have no resource costs.

Since the objective function and constraints in the above problem are separable, selection of preferred diplomatic activities can be treated separately from allocation of resources.

1. Allocation of Resources

Find $a_1,\ldots,a_n$ to maximize $e_1a_1+\ldots+e_na_n$

Subject to $c_1a_1+\ldots+c_na_n \leq B$

$a_i = 0$ or 1 for every i

The general idea in solving this problem is to select activities one at a time, in order of decreasing e_i/c_i, until the total cost of all activities selected reaches B.

Let r be the index of activities ranked in order of highest to lowest e_i/c_i. Thus r=1 corresponds to the maximum e_i/c_i, r=2 to the next highest, and so forth. Rewrite the problem as:

$$\text{Maximize} \quad \sum_{r=1}^{n} e_r a_r$$

$$\text{Subject to} \quad \sum_{r=1}^{n} c_r a_r \leq B$$

$$a_r = 0 \text{ or } 1 \text{ for all } r$$

Let S_r be the total cost of selecting all activities up to and including the rth activity. Thus $S_r = \sum_{j=1}^{r} c_j$. Let $S_0 = 0$. The following sequential algorithm can now be used to solve the problem:

(1) Initialize $r = 1$, $a_j = 0$ for $i = 1,\ldots,n$

(2) Compute $S_r = S_{r-1} + c_r$

(3) If $S_r > B$, go to (7)

If $S_r = B$, set $a_r = 1$ and go to (12)

If $S_r < B$, go to (4)

(4) Set $a_r = 1$ and $r = r + 1$

(5) If $r = n + 1$, go to (12)

(6) Go to (2)

(7) Set $j = r + 1$

(8) If $j = n + 1$, go to (12)

(9) If $S_{r-1} + c_j < B$, go to (10)

If $S_{r-1} + c_j = B$, set $a_j = 1$ and go to (12)

If $S_{r-1} + c_j > B$, go to (11)

(10) Set $a_j = 1$, $S_{r-1} = S_{r-1} + c_j$

(11) Set $j = j + 1$ and go to (8)

(12) Stop

The output of this algorithm is a vector of activity levels, $(a_1,...,a_n)$, that yields the highest overall effectiveness without exceeding a total cost of B.

2. Selection of Preferred Diplomatic Activities

Let $a_{n+1},...,a_{n+d}$ be the activity levels of d activities that have no resource costs (i.e., diplomatic actions). The problem is to:

Maximize $e_{n+1}a_{n+1}+...+e_{n+d}a_{n+d}$

Subject to $\sum_I a_i = 1$ for each set I of mutually exclusive activities

$a_i = 0$ or 1 for $i = n+1,...,n+d$

Diplomatic activities are always formulated in sets of at least two mutually-exclusive activities, since any diplomatic action has at least one mutually-exclusive alternative (namely, not to take the action).

The solution to this problem is straightforward. For each set I of mutually-exclusive activities, find the one member of the set that has the highest effectiveness coefficient e_i:

$$\text{For each } I \text{ find } i \text{ such that } e_i = \max_j \left\{ e_j \text{ for all } j \in I \right\}$$

In the hypothetical problem analyzed in Chapter VI, a_9 and a_{10} were mutually-exclusive diplomatic activities. Furthermore, e_{10} was greater than e_9. Hence the preferred solution was $a_9 = 0$ and $a_{10} = 1$.

APPENDIX B

SUPPLEMENTARY CALCULATIONS FOR CHAPTER VI

1. Derivation of Final Weight for Each Objective

The intermediate weights relating each level of aims to the next highest level are given. It is desired to compute the final weights, which relate the objectives (X-level aims) to the ultimate goal V. The procedure is to compute new intermediate weights relating the objectives to the Z-level goals using equation (7) of Chapter IV, and then to use these weights again in equation (7) to relate the objectives to V.

a. Calculation of X-to-Z-level Intermediate Weights

From equation (7) developed in Chapter IV, the computing formula is:

$$w_{xjzp} = \sum_{k=1}^{4} w_{xjyk} w_{ykzp} \qquad \text{for } j=1,\ldots,5; \quad p=1,2$$

$$= w_{xjy1}w_{y1zp} + w_{xjy2}w_{y2zp} + w_{xjy3}w_{y3zp} + w_{xjy4}w_{y4zp}$$

$$w_{x1z1} = .4(.2) + .3(.1) + 0(.3) + 0(.4) = 0.11$$

$$w_{x2z1} = .6(.2) + 0(.1) + 0(.3) + 0(.4) = 0.12$$

$$w_{x3z1} = 0(.2) + .6(.1) + .2(.3) + 0(.4) = 0.12$$

$$w_{x4z1} = 0(.2) + .1(.1) + .2(.3) + 0(.4) = 0.07$$

$$w_{x5z1} = 0(.2) + 0(.1) + .6(.3) + 0(.4) = 0.18$$

$$w_{x6z1} = 0(.2) + 0(.1) + 0(.3) + 1.0(.4) = 0.40$$

$$\sum_{j=1}^{6} w_{xjz1} = 1.00$$

$$w_{x1z2} = .4(0) + .3(.4) + 0(.6) + 0(0) = 0.12$$

$$w_{x2z2} = .6(0) + 0(.4) + 0(.6) + 0(0) = 0.00$$

$$w_{x3z2} = 0(0) + .6(.4) + .2(.6) + 0(0) = 0.36$$

$$w_{x4z2} = 0(0) + .1(.4) + .2(.6) + 0(0) = 0.16$$

$$w_{x5z2} = 0(0) + 0(.4) + .6(.6) + 0(0) = 0.36$$

$$w_{x6z2} = 0(0) + 0(.4) + 0(.6) + 1.0(0) = 0.00$$

$$\sum_{j=1}^{6} w_{xjz2} = 1.00$$

b. <u>Calculation of X-to-V-level Final Weights</u>

$$w_{xjvr} = \sum_{p=1}^{2} w_{xjzp} w_{zpvr} \qquad \text{for } p=1,2; \quad r=1$$

$$= w_{xjz1} w_{z1v1} + w_{xjz2} w_{z2v1}$$

$$W_{x1v1} = .11(.7) + .12(.3) = .113 = w_1$$

$$w_{x2v1} = .12(.7) + 0(.3) = .084 = w_2$$

$$w_{x3v1} = .12(.7) + .36(.3) = .192 = w_3$$

$$w_{x4v1} = .07(.7) + .16(.3) = .097 = w_4$$

$$w_{x5v1} = .18(.7) + .36(.3) = .234 = w_5$$

$$w_{x6v1} = .40(.7) + 0(.3) = .280 = w_6$$

$$\sum_{j=1}^{6} w_{xjv1} = 1.000$$

2. Calculation of Activity Effectiveness Coefficient

a. <u>Summary of Objective SLs Resulting from Activities</u>

$\vec{x}^1 = (.5,0,0,0,0,0)$ $\quad$ $\vec{x}^2 = (.5,0,0,0,0,0)$

$\vec{x}^3 = (0,1.0,0,0,0,0)$ $\quad$ $\vec{x}^4 = (0,0,.6,0,0,0)$

$\vec{x}^5 = (0,0,.2,0,0,0)$ $\quad$ $\vec{x}^6 = (0,0,.2,0,0,0)$

$\vec{x}^7 = (0,0,0,.5,0,0)$ $\quad$ $\vec{x}^8 = (0,0,0,.5,0,0)$

$\vec{x}^9 = (0,0,0,0,1.0,0)$ $\quad$ $\vec{x}^{10} = (0,0,0,0,0,1.0)$

b. Weighted Additive Value Function

$$U(\vec{q}) = .113x_1 + .084x_2 + .192x_3 + .097x_4 + .234x_5 + .280x_6$$

c. Calculating Effectiveness Coefficients

$$e_1 = U(\vec{q}^{\,1}) = .113(.5)+.084(0)+.192(0)+.097(0)+.234(0)+.280(0)=.0565$$

$$e_2 = U(\vec{q}^{\,2}) = .113(.5)+.084(0)+.192(0)+.097(0)+.234(0)+.280(0)=.0565$$

$$e_3 = U(\vec{q}^{\,3}) = .113(0)+.084(1.0)+.192(0)+.097(0)+.234(0)+.280(0)=.0840$$

$$e_4 = U(\vec{q}^{\,4}) = .113(0)+.084(0)+.192(.6)+.097(0)+.234(0)+.280(0)=.1152$$

$$e_5 = U(\vec{q}^{\,5}) = .113(0)+.084(0)+.192(.2)+.097(0)+.234(0)+.280(0)=.0384$$

$$e_6 = U(\vec{q}^{\,6}) = .113(0)+.084(0)+.192(.2)+.097(0)+.234(0)+.280(0)=.0384$$

$$e_7 = U(\vec{q}^{\,7}) = .113(0)+.084(0)+.192(0)+.097(.5)+.234(0)+.280(0)=.0485$$

$$e_8 = U(\vec{q}^{\,8}) = .113(0)+.084(0)+.192(0)+.097(.5)+.234(0)+.280(0)=.0485$$

$$e_9 = U(\vec{q}^{\,9}) = .113(0)+.084(0)+.192(0)+.097(0)+.234(1.0)+.280(0)=.2340$$

$$e_{10} = U(\vec{q}^{\,10}) = .113(0)+.084(0)+.192(0)+.097(0)+.234(0)+.280(1.0)=.2800$$

APPENDIX C

OPTIMAL ALLOCATION OF RESOURCES AMONG COUNTRY PROGRAMS

1. Country planners allocate funds within their country programs so as to maximize the country-based value function. In so doing they solve the following problem:

$$\text{Find } \vec{a}^{k} \text{ to maximize } \quad U_k(\vec{a}^{k})$$
$$\text{Subject to} \quad c(\vec{a}^{k}) \leq B_k \qquad \text{(C1)}$$

where the subscript/superscript k denotes the kth country $(k=1,\ldots,K)$.

Let U_k^* be the optimal value of U_k. This will be a function of B_k because in general a different budget will result in a different allocation of resources and a higher or lower value of U_k. Hence,

$$U_k^* = U_k^*(B_k)$$

2. Central planners allocate the total budget among the K countries in order to maximize the aggregate value function. They solve the problem:

$$\text{Find } B_1,\ldots,B_K \text{ to maximize } \quad \sum_{k=1}^{K} w_k U_k^*(B_k)$$
$$\text{Subject to} \quad \sum_{k=1}^{K} B_k = B \qquad \text{(C2)}$$

The central planning problem can be solved by the method of Lagrange Multipliers:

$$L(B_1,\ldots,B_K) = \sum_{k=1}^{K} w_k U_k^*(B_k) - \lambda\left(B - \sum_{k=1}^{K} B_k\right)$$

$$\frac{\partial L}{\partial B_k} = w_k \frac{\partial U_k^*}{\partial B_k} - \lambda = 0$$ (first order necessary condition for optimality)

hence $\lambda = w_k \dfrac{\partial U_k^*}{\partial B_k}$ for every k, which implies that the quantities $w_k \dfrac{\partial U_k^*}{\partial B_k}$ are all equal. In other words, the optimal allocation can be achieved only if all $w_k \dfrac{\partial U_k^*}{\partial B_k}$ are equal.

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13. ABSTRACT

Foreign policy analysis is defined as an evaluation of the benefits and costs of alternative collections of overseas activities, considering the relationship of their consequences to foreign policy goals and interests. The need for a quantitative methodology to supplement traditional methods of policy analysis is discussed. A quantitative policy analysis methodology is developed which consists of: a predictive model that forecasts objectively-verifiable consequences of the proposed activities; and a weighted additive value function defined over consequences that measures the effectiveness of each alternative. The value function reflects the extent to which desired consequences are achieved by a given alternative and the relationship of desired consequences to motivating goals and interests. The problem of selecting an optimal allocation of resources and preferred mix of diplomatic activities is formulated as an integer program and a sequential algorithm is developed for its solution. Extensions to a dynamic, multi-year planning model and modifications to permit decentralized planning are discussed.

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